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THESIS

IMPLICATIONS OF TRANSACTION COSTS FOR ACQUISITION PROGRAM COST BREACHES

by

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June 2013

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It is generally accepted that cost growth in federal major defense acquisition programs (MDAPs) is partially attributable to inaccurate cost estimates. Cost analysts exhaustively analyze manpower and resources to provide accurate estimates, however the influence of transaction costs is often ignored in traditional cost estimates. This thesis investigates the association between cost growth and transaction costs, the real cost of business negotiations and program management. We collect MDAP cost threshold breach data and cross reference it with a proxy for MDAP transaction costs (Systems Engineering/Program Management Costs) to determine whether a correlation exists. We use multiple logistic regression models to analyze the binary outcome of breach or no breach. The results show that for MDAPs with cost-plus contracts there is a statistically significant relation between the likelihood of a cost threshold breach occurring and the relative magnitude of the MDAP's transaction costs; no such relation exists for fixed price contracts. Although these results show an association between cost threshold breaches and transaction costs, there is no evidence of causality between these two variables and our exploration of causality is a topic for future research.

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ABSTRACT

It is generally accepted that cost growth in federal major defense acquisition programs (MDAPs) is partially attributable to inaccurate cost estimates. Cost analysts exhaustively analyze manpower and resources to provide accurate estimates. However, the influence of transaction costs is often ignored in traditional cost estimates. This thesis investigates the association between cost growth and transaction costs, the real cost of business negotiations and program management. We collect MDAP cost threshold breach data and cross reference it with a proxy for MDAP transaction costs (Systems Engineering/Program Management Costs) to determine whether a correlation exists. We use multiple logistic regression models to analyze the binary outcome of breach or no breach. The results show that for MDAPs with cost-plus contracts there is a statistically significant relation between the likelihood of a cost threshold breach occurring and the relative magnitude of the MDAP's transaction costs; no such relation exists for fixed price contracts. Although these results show an association between cost threshold breaches and transaction costs, there is no evidence of causality between these two variables and our exploration of causality is a topic for future research.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
ACWP	Actual Cost of Work Performed
APB	Acquisition Program Baseline
APUC	Acquisition Procurement Unit Cost
BAC	Budget At Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CAPE	Cost Analysis and Performance Evaluation
CDSR	Cost Data Summary Report
CE	Current Estimate
CSDR	Cost and Software Data Reporting
CWBS	Contract Work Breakdown Structure
DAMIR	Defense Acquisition Management Information Retrieval
DAU	Defense Acquisition University
DCARC	Defense Cost and Resource Center
DDCA	Deputy Director, Cost Assessment
DoD	Department of Defense
EAC	Estimate at Completion
EVM	Earned Value Management
FY	Fiscal Year
GAO	Government Accountability Office
JCIDS	Joint Capabilities Integration and Development System
MAIS	Major Automated Information System
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MILCON	Military Construction
OLS	Ordinary Least Squares
OSD	Office of the Secretary of Defense

O&M	Operations and Maintenance
PAUC	Program Acquisition Unit Cost
PM	Program Manager
PMB	Performance Measurement Baseline
PPBE	Planning, Programming, Budgeting and Execution
RDT&E	Research, Development, Testing and Evaluation
R&D	Research and Development
SAR	Selected Acquisition Report
SE/PM	System Engineering / Program Management
TCE	Transaction Cost Economics
TRL	Technology Readiness Level
WBS	Work Breakdown Structure

EXECUTIVE SUMMARY

The Department of Defense (DoD) 2012 major defense acquisition program (MDAP) portfolio is estimated at $1.6 trillion, and contains 86 MDAPs. While this is a reduction in the total cost and number of MDAPs compared against 2011, the total cost of these programs has increased by more than $400B since their first full cost estimate (Government Accountability Office 2013, 6). Given the large scale of spending, life cycle cost estimates for MDAPs, which include the acquisition cost estimates, should be credible information for budgetary and policy decisions.

DoD decision makers use three separate cost estimates: from the program office, from a DoD component, and an independent estimate performed by Office of Secretary of Defense Cost Analysis and Performance Evaluation (OSD CAPE). Despite these efforts, the number of MDAPs that sustain cost breaches (cost overruns of 10% or greater) suggests that acquisition costs are frequently underestimated.

Transaction cost, the real cost of business negotiations and program management, is a component of cost estimates that is often overlooked when estimating costs of a program or system. This research explores the possibility that transaction costs are one possible cause for low cost estimates of MDAPs and the resulting cost breaches. This thesis seeks to answer the following questions:

Is there a relation between MDAP transaction costs and cost breaches?

Are cost breaches related to the amount, or percentage of total costs, spent on MDAP transaction costs?

By using a proxy for transaction costs (systems engineering and program management [SE/PM] costs), this thesis attempts to measure the relationship between transaction costs and cost breaches. While most accounting systems do not capture transaction costs as a separate category, the SE/PM category would certainly include such costs. It is logical to suppose that programs that are more complex or have technical difficulties are more likely to experience higher transaction costs which may not have been anticipated in the original cost estimate. Consequently, such programs would be

more likely to see cost breaches. This research analyzes the level of SE/PM expenditures in major defense acquisition programs to determine whether a relationship exists between transaction costs and cost breaches. A brief discussion about the data collection process and three models used to answer the proposed thesis questions follows.

The research was done in two parts: the collection of MDAP cost information to build a database; and the selection of an appropriate model to analyze the data. The database paired program breaches and SE/PM costs. Program cost breach information found in the MDAP selected acquisition report was coupled with SE/PM cost ratios that were calculated using data obtained from MDAP cost summary data reports. For purposes of this research, a cost breach is defined as a cost overrun of 10% or greater.

Recognizing that transaction costs may not be the only factor associated with cost breaches, data were collected for other factors such as contract type and "maturity"—defined in this report as the time in years since program initiation. While there are many more variables that may be related to cost breaches, contract type and maturity were selected based on the availability of relevant data from the two databases used, Defense Acquisition Management Information Retrieval (DAMIR) and Defense Cost and Resource Center (DCARC). Ideally, the development of a multivariate model that has predictive power for MDAP cost breaches could serve as a useful tool.

Logistic regression is designed for use with binary-outcome dependent variable models and was therefore the logical choice to examine the occurrence of program breaches. Logistic regression models use maximum likelihood estimators, or logits, which are the natural logarithm of the odds ratio for a particular outcome. Fixed effects logistic regression and population averaged logistic regression were both considered. Fixed effects logistic regression looks within programs for changes in the EAC SE/PM cost ratio and is a useful tool for describing the impact of short run changes in the MDAP. In the end, the population averaged logit model was selected because it looks across programs to measure changes in the SE/PM cost ratio and is most useful in measuring long run effects.

In the first model, MDAP cost breaches were compared against estimate at completion (EAC) SE/PM cost ratios and analyzed using logit fixed effects regression and logit population averaged regression. This analysis tested the hypothesis that the probability of an MDAP sustaining a cost breach is related to its EAC SE/PM cost ratio. The logit population averaged regression model indicates a positive relationship that is significant at the 5% ($p = 0.05$) level between the likelihood of a cost breach occurring and EAC SE/PM cost ratio. The salient information that the logit population averaged model can provide includes the average marginal effects and marginal effects values which describe the effect of the independent variables on the dependent variable. For instance, based on across program observations the logit population averaged model shows that the average marginal effect of the independent variable on the dependent variable is 0.80. This means that, on average, for a 1% increase in the SE/PM cost ratio there is a corresponding 0.80% increase in the likelihood that a cost breach will occur.

In the second model an explanatory variable was added: program maturity, considered in this report to be the length of time (in years) since the program entered Milestone B. The rationale to consider the effect of program maturity against cost breaches is that older programs are expected to have less uncertainty and risk than younger programs. This model tested the null hypothesis that there is no relation of cost breaches with EAC SE/PM cost ratio and program maturity as defined in this report. The model was analyzed using logit fixed effects regression and logit population averaged regression. While program maturity alone did not yield statistically significant results, there is evidence that the maturity of a program affects the probability of a cost breach occurring in the model. The average marginal effect of maturity in the population averaged logit model is 0.70 and for EAC SE/PM cost ratio the average marginal effect is 0.89.[1] This means that, on average, a one unit (1%) change in the maturity of an MDAP equates to a 0.70% change in the likelihood of a cost breach occurring. Similarly, a one unit (1%) change in the EAC SE/PM cost ratio will result in a 0.89% change, on average, in the likelihood of an MDAP incurring a cost breach.

[1] The statistically significant results that produced a marginal effect on the dependent variable were calculated using the natural logarithm of maturity, as explained in Chapter IV.

The third model introduced an additional explanatory variable to the previous model: contract type. This model compared MDAP cost breaches to EAC SE/PM cost ratios, program maturity and contract type. The rationale for considering contract type is that acquisitions professionals generally accept the notion that firm fixed price contracts are frequently negotiated between the government and contractors for less risky programs and cost-plus contracts are negotiated for projects which have greater uncertainty and are perceived to be more risky (Government Accountability Office 2009b). Logic suggests that riskier MDAPs should have cost-plus contracts and experience more cost breaches than their less risky counterparts. This last model tests the null hypothesis that there is no relation between cost breaches and EAC SE/PM cost ratio, program maturity and MDAP contract type. Only cost-plus contracts were observed to have statistically significant results, at the 10% level. For cost-plus contracts, including the maturity of a program has an effect on the probability of a cost breach occurring. According to the population averaged model, the average marginal effect of maturity is 0.21 and EAC SE/PM cost ratio is 1.00. This means that, on average, for a one unit (1%) change in program maturity the likelihood of a cost breach occurring will change by 0.21%. Moreover, for a one unit (1%) change in the EAC SE/PM cost ratio the likelihood of a cost breach occurring will change by 1.00%, on average. The results of this last model show that for cost-plus contracts as the EAC SE/PM cost ratio increases there is a corresponding increase in the probability of a cost breach occurring. Although there is correlation between SE/PM cost ratio and cost breaches, it cannot be assumed that transaction costs are a causal factor for cost breaches.

In this research, the model which included the explanatory variables maturity and cost-plus contract types yielded statistically significant results and had the largest values for the average marginal effects of EAC SE/PM cost ratio. These contracts exhibited relationships between (1) the EAC SE/PM cost ratio and the likelihood of a cost breach occurring; and (2) program maturity and the likelihood of a cost breach occurring. Future work to better understand the relationship between transaction costs and cost estimation may require the development of a more complex model. Hopefully, this thesis will provide a useful foundation toward building a better model.

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I. INTRODUCTION

The acquisition process is the means by which the federal government acquires supplies or services by contract. For the Department of Defense (DoD), the acquisition process is used to provide support and services for military operations. The sequential three-step process for acquiring supplies and services is: (1) the Joint Capabilities Integration and Development System (JCIDS), which identifies system requirements; (2) the Planning, Programming, Budgeting and Execution (PPBE) process, which allocates resources; and (3) the acquisition process, which obtains the supplies or services that satisfy defense needs (Schwartz 2013, 3). This acquisition process includes the "design, engineering, construction, testing, deployment, sustainment, and disposal of weapons or related items purchased from a contractor" (Acquisition Central 2013) and is managed by the program manager (PM).

The program manager is "the designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs." The PM reports program cost, schedule, and performance information to the milestone decision authority (MDA) (Department of Defense Instruction 5000.01 2003).[2] Weapon system acquisitions fall into three categories: ACAT I, II or III. Major defense acquisition programs (MDAPs) ACAT I acquisition programs are estimated to have expenditures greater than \$365M in research, development, technology and engineering (RDT&E) or \$2.190B in procurement, including all planned increments, in FY 2000 constant dollars; in addition, programs may be designated as ACAT I by the Under Secretary of Defense for Acquisition, Technology and Logistics (Defense Acquisition University 2011b). ACAT I programs are commonly referred to as major defense acquisition programs (MDAPs). Acquisition programs that do not meet the requirements for ACAT I are categorized as ACAT II or III programs. This thesis will focus on cost overruns for ACAT I programs.

[2] The MDA has overall responsibility for the program and is responsible for reporting program cost, schedule and performance information to higher authority, including Congress (Department of Defense Instruction 5000.01 2003).

Program managers use the systems engineering process, an overarching method that transitions "from a stated capability to an operationally effective and suitable system," (Defense Acquisition University 2011b) to effectively manage their programs. The systems engineering process is applied throughout the entire life cycle of a program, and includes everything from system design and development to system operation, disposal and life cycle costing.[3] Cost estimate inaccuracies are identified as a leading cause of system cost growth (Blanchard and Fabrycky 2010, 567). This report seeks to better understand cost overruns by looking at transaction costs, a significant component of program management, and their relation to MDAP cost threshold breaches. In particular, the research looks at these questions:

- Is there a correlation between MDAP transaction costs and acquisition cost threshold breaches?
- Do underestimated transaction costs contribute to MDAP cost threshold breaches?
- Are cost threshold breaches related to the *amount*, or percentage of total costs, spent on MDAP transaction costs?

A. COST OVERRUNS IN MAJOR DEFENSE ACQUISITION PROGRAMS

In this report, cost overruns are defined using earned value management (EVM) terms. The DoD has used the EVM system since 1996 to evaluate contractor management systems (Defense Acquisition University 2011b). According to EVM, a cost overrun situation occurs whenever the actual cost of the work performed to complete the project is greater than the budgeted cost of the work required to complete the project. The extent of the cost overrun can be determined by evaluating the difference between the actual cost and budgeted cost. The severity of a cost overrun may warrant certain actions to be taken by the program manager. EVM and the consequences of sustaining a cost overrun will be discussed further in Chapter II.

The prevalence of cost overruns in major defense acquisition programs suggests that there may be a component of cost estimations that is not accurately considered. As defined by the Defense Acquisition University (DAU), a cost overrun is "the amount by

[3] For more information on life cycle costing see Benjamin S. Blanchard and Wolter J. Fabrycky, *Systems Engineering and Analysis* 5th Ed. (Boston: Prentice Hall, 2011), 566–631.

which a contractor exceeds the estimated cost and/or the final limitation (ceiling) of the contract" (Defense Acquisition University 2011b). The Government Accountability Office (GAO) reported that the 96 active MDAPs in FY 2011 sustained acquisition cost growth of $74.4B, collectively. Furthermore, about 60% of this cost growth can be attributed to procurement costs (exclusive of procurement quantity changes) and research and development costs (United States Government Accountability Office 2012). A 2011 GAO report stated that "inaccurate cost estimates are responsible for the strongest correlation with net cost growth changes and are associated with 40 percent of the accumulated cost overruns" (GAO 2011, 2).[4] A 2007 RAND study on the cost growth in DoD weapons systems analyzed total program and procurement cost growth for 46 programs. The study determined that the cost growth ratio across all programs was 1.46, or 46 percent, more than the cost estimate for Milestone B (program initiation) (Obaid Younossi et. al 2007, xvi).

A recent study looked at Department of Defense contractors and found that they earn above-"normal" profits when compared to non-defense industry peers. It reports that "cost growth occurs steadily throughout the program lifespan" and goes on to further suggest "that younger programs are not performing better than older programs" (Wang and San Miguel 2012). This corroborates the Defense-Industrial Initiatives Group, Center for Strategic and International Studies findings in their report entitled Cost and Time Overruns for Major Defense Acquisition Programs.

Perhaps there are acquisition costs that may not be completely reflected in life cycle cost estimations: transaction costs. Is it possible that underestimated transaction costs have been contributing to cost growth for MDAPs for decades? Cost estimates that better account for transaction costs should be more accurate (relative to original estimates). This thesis addresses transaction costs, a component of system cost that is not well considered in cost estimates. Is there a correlation between transaction costs and cost estimate overruns in MDAPs? A better understanding of transaction costs may help to

[4] Information about improving cost estimating methodology can be found in the GAO Cost Estimating and Assessment Guide, GAO-09-3SP, "Best Practices for Developing and Managing Capital Cost Programs."

explain the difference between actual and estimated costs in MDAPs, which could lead to more realistic cost estimates and better forecasting of cost breaches.

To measure transaction costs, this study uses a proxy measure that incorporates systems engineering and program management costs. According to MIL-STD-881C, system engineering is defined as "the technical and management efforts of directing and controlling a totally integrated engineering effort of a system or program" (Department of Defense 2011, 221). Program management is defined as "the business and administrative planning, organizing, directing, coordinating, controlling, and approval actions designated to accomplish overall program objectives, which are not associated with specific hardware elements and are not included in systems engineering" (Department of Defense 2011, 222). The similarities in the definitions for systems engineering and program management can lead program managers and contractors to different interpretations for allocating program costs. In either case, whether the costs are allocated to systems engineering or program management, it is reasonable to assume that a combination of the two will provide an approximate, albeit indirect, measure of the transaction costs experienced by a program.

This study seeks to understand the impact of transaction costs on MDAP cost overruns. Specifically, it looks at significant cost overruns, defined as "cost breaches." A cost breach occurs when program costs exceed the approved acquisition program baseline (APB) by 10%, or greater. Cost breaches and MDAP APBs are discussed in further detail in subsequent sections of this report. For an MDAP that program managers feel may incur a cost breach it seems reasonable to assume that the SE/PM costs may increase as managers proactively respond to the program manager's direction. Programs that have recently experienced a cost breach may also see increasing SE/PM costs as a reaction to a program manager's decisions and direction. Can cost breaches be related to the amount of SE/PM cost, as a percentage of total cost, in a program?

B. DEPARTMENT OF DEFENSE (DOD) COST ESTIMATION

The purpose of cost estimation in the DoD is to provide a reasonably good prediction of the costs associated with a program through its operational life—that is, to estimate all the major components of life cycle costs. There are many different ways to define life cycle costs, however it is generally accepted that life cycle costs are the sum of the following elements: research and development (R&D) costs, production and construction costs, operation and support costs, and retirement and disposal costs (Blanchard and Fabrycky 2011). Acquisition costs, which consist of the R&D costs and the production and construction costs, compose a significant portion of a program's estimated life cycle cost.

For the purpose of this report, cost estimation in acquisitions is considered to be "the summation of individual cost elements, using established methods and valid data, to estimate the future costs of a program, based on what is known today" (Government Accountability Office 2009a). In a 1972 GAO report titled "Theory and Practice of Cost Estimating for Major Acquisitions," it was noted that DoD cost estimating techniques across DoD programs were inconsistent in their level of detail and that the cost estimating techniques used by the DoD programs varied widely.

GAO believed these disparities typically resulted in inaccurate, low cost estimates. In response to these findings and in the same 1972 GAO report, GAO published its first version of "Basic Characteristics of Credible Cost Estimates," a descriptive listing of basic characteristics that GAO advises should be found in program cost analyses to this day. Although this guidance has been in existence for years, GAO case studies provide evidence that in many programs the guidance has not been followed. Some of the problems noted in that report are:

- Known costs had been excluded without adequate or valid justification;
- Historical cost data used for computing estimates were sometimes invalid, unreliable, or unrepresentative;
- Understanding the proper use of the estimates was hindered because the estimates were too low;
- Readily retrievable cost data that could serve in computing cost estimates for new weapon systems were generally lacking; and
- Organized and systematic efforts were not made to gather actual cost information to achieve comparability between data collected on various weapon systems or to see whether the cost data the contractors reported were accurate and consistent.

In an effort to help government managers and auditors ensure credible cost estimates, the GAO published the "GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs" in 2009. The majority of the guide (Chapters 1–17) is used to discuss best practices for obtaining credible cost estimates and the relation between these estimates and earned value management (EVM) (Government Accountability Office 2009a, 1). EVM is the system used by DoD to evaluate contractor management systems (Defense Acquisition University 2011b) and is explained in the next chapter. The latter portion of the guide (Chapters 18–20) provides guidance for "integrating cost estimation, system development oversight, and risk management" to the program's life cycle costs (Government Accountability Office 2009a, 2).

In 1992, Office of the Secretary of Defense Cost Analysis Improvement Group (OSD CAIG) promulgated the "DoD Cost Analysis Guidance and Procedures" (DoD 5000.4-M) to improve the reliability of DoD cost estimates. The CAIG function is now conducted by Director, Cost Assessment and Program Evaluation (D, CAPE) within OSD and is responsible for overseeing DoD cost estimation policy and procedures and providing independent life cycle cost estimates for MDAPs (Defense Acquisition University 2011b, B-54).[5] In addition to the independent life cycle cost estimate, DoD Instruction 5000.2 and DoD 5000.2-M require that a program office estimate and DoD component cost analysis estimate also be performed (Department of Defense 1992, 8). These three estimates are based on the MDAP cost analysis requirements description (CARD), a document which provides an overview of the "technical and programmatic" features of an acquisition program (Defense Acquisition University 2011b, B-56). The Director of CAPE considers these estimates and provides this information for consultation to the Under Secretary of Defense for Acquisition, Technology and Logistics (USDAT&L) when USDAT&L is the milestone decision authority (MDA) (i.e., ACAT ID MDAPs) (Congress 2009, Section 101). In accordance with DoDI 5000.02, Enclosure 4, Table 2, independent cost estimates for ACAT ID programs must be provided by OSD

[5] A responsibility of the Office of Cost Assessment and Program Evaluation (CAPE) is to provide "independent analytic advice" to the Secretary of Defense on the cost-effectiveness of defense systems (Cost Assessment and Program Evaluation 2013a).

CAIG before entering the Technology Development phase (Milestone A), the Engineering and Manufacturing Development phase (Milestone B, or program initiation), the Production and Deployment phase (Milestone C) and the full-rate production decision review.

Cost estimates are expected to change and presumably become more accurate as the program matures. These refinements are largely due to lessening uncertainty surrounding the specific program requirements and less outstanding expenditures remaining as the program progresses to completion. In order to ensure a realistic and accurate cost estimate it is important that MDAP cost estimates be periodically re-evaluated and updated to account for requirements changes, actual cost expenditures instead of estimated costs and the latest version of the program's schedule (Government Accountability Office 2009a, 37). GAO states that "relying on a standard process that emphasizes pinning down the technical scope of the work, communicating the basis on which the estimate is built, identifying the quality of the data, determining the level of risk, and thoroughly documenting the effort should result in cost estimates that are defensible, consistent, and trustworthy" (Government Accountability Office 2009a, 12).

C. TRANSACTION COSTS

Transaction costs are the costs associated with "source selection, periodic competition and renegotiation, contract negotiation and management, performance measuring and monitoring and dispute resolutions" (Angelis et al. 2008). Transaction costs are derived from the complexity and riskiness of the work to be accomplished. Thus, transaction costs represent a "cost of doing business" that may not be completely captured in standard WBS estimates.

Traditional cost estimation is derived from the Work Breakdown Structure (WBS); however, due to the prevalence of cost overruns and inaccurate cost estimates, it can be deduced that something is missing from this analysis of cost estimation. Transaction costs may be the delta between actual and estimated costs that is difficult to capture and assess.

In general, a program has two types of costs: contract costs and transaction costs. Contract costs are the costs of production and are usually captured in the WBS.

Transaction costs can be considered motivation or coordination costs and may not be adequately captured in the WBS (Angelis et al. 2008).

Total Program Cost = Transaction Costs + Contract Costs;

Transaction Cost = Coordination Costs + Motivation Costs;

Coordination costs include search and information costs; bargaining and decision costs; policing and enforcement costs. These costs are affected by market competition (contestability), asset specificity, and the recurrence or frequency of a transaction. Asset specificity, a manufacturer's specialization in the production of a system or machine, may result in the government becoming reliant on a sole provider and lead to opportunistic behavior by the manufacturer. Motivation costs are those costs which promote productive efforts and provide incentives to encourage investment, as well as those costs which deter unproductive bargaining and opportunistic behavior. Motivation costs are impacted by the complexity of the contract, the uncertainty or amount of risk that a contract presents and the contract type. For more information about transaction costs see "Applying Insights from Transaction Cost Economics (TCE) to Improve DoD Cost Estimation" (Angelis et al. 2007).

For an MDAP, there are many effective ways to reduce coordination and motivation costs:

- Reduce complexity
- Reduce uncertainty
- Increase measurement and monitoring
- Actively deter bad behavior
- Mitigate uncertainty from asset specificity with incentives
- Increase contestability

A better understanding of transaction costs may contribute to improving cost estimates and reducing the number of MDAPs which experience a cost breach.

D. ASSESSING TRANSACTION COSTS

Transaction costs are difficult to assess because they are not easily identified and seldom captured in the accounting records. Therefore, a proxy must be used to measure the effect of transaction costs due to the lack of data. Angelis, et.al. have suggested the use of the SE/PM ratio as such a proxy. The SE/PM ratio is defined as SE/PM Cost divided by Total Program Cost, Equation 1.1.

$$\text{SE / PM Cost Ratio} = \frac{\text{SE / PM Costs}}{\text{Total Cost}} \tag{1.1}$$

The SE/PM cost ratio seems an appropriate proxy for transaction costs because program management costs and transaction costs are both defined, in part, as costs associated with contract management (i.e., cost, schedule) and performance measuring and monitoring. Due to differences in program accounting practices and varying interpretations for classifying costs as Systems Engineering or Program Management, it is prudent to collect the sum total of program SE/PM costs to ensure that the correct costs are included in the data that is gathered.

This study will analyze the SE/PM cost ratio, as a proxy for transaction costs, of MDAPs and the potential correlation between the SE/PM ratios and cost breaches. Determining the nature of any potential relationship between the SE/PM cost ratio and the number of cost breaches experienced by a program would test the hypothesis that programs with higher SE/PM cost ratios will experience more cost overruns than programs with lower SE/PM cost ratios. It is presumed that programs with higher SE/PM cost ratios are in riskier contractual relationships and have higher transaction costs and will experience more cost overruns than those programs with lower SE/PM cost ratios.

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II. COST BREACHES IN MAJOR DEFENSE ACQUISITIONS PROGRAMS

Reining in cost growth for MDAPs has been problematic to the Department of Defense (DoD) for many years (Arena et al. 2006). The establishment of Selected Acquisition Reports (SARs) in 1967 was an early attempt to better monitor MDAP performance. SARs contain critical MDAP performance, cost and schedule information for use within the DoD and the Congress.[6] Cost threshold breaches, by program appropriation category, are quickly and easily identifiable within the SAR. If a program cost threshold breach occurs, a brief explanation of how or why the cost threshold breach occurred is also found within the SAR. The default threshold value for a cost breach to occur is 10% cost growth. The various types of cost breaches and their cost appropriation categories are explained later in this chapter.

In 1981, Senator Samuel Nunn and Congressman David McCurdy introduced the Nunn-McCurdy Amendment (10 U.S.C. § 2433 2006) in an effort to curb MDAP cost growth by holding the Department of Defense publicly accountable to Congress for their fiscal management of MDAPs. The Nunn-McCurdy Amendment became law with the FY 1983 Department of Defense Authorization Act, which establishes consequences for MDAPs which exceed cost thresholds. These consequences include that the Secretary of Defense provide Congress with program cost estimates using original and current requirements, as well as certification to Congress that the unit costs are reasonable and that the management structure of the program is adequate to control future costs (Government Accountability Office 2009a, 310–311).

A. TYPES OF COST BREACHES IN DOD

This thesis focuses on six important categories of appropriations where cost breaches often occur: acquisition procurement unit cost (APUC); program acquisition unit cost (PAUC); procurement; research, development, testing and evaluation (RDT&E);

[6] The information found in the SAR provides a "quick look" summary of the MDAP's ability to meet cost, performance and schedule objectives and remain within the thresholds agreed upon by the Program Manager and Defense Acquisition Executive.

military construction (MILCON); and acquisition-related operations and maintenance (O&M). These categories of appropriations were selected due to their availability in the Defense Acquisition Management Information Retrieval (DAMIR) database. APUC and PAUC were selected for their relevance to cost overruns as defined by Nunn-McCurdy cost breaches. Procurement and RDT&E appropriations are often identified in the SAR as the appropriation which incurred the cost threshold breach, thus providing a logical explanation for their inclusion in the data set. MILCON and acquisition-related O&M appropriations, though infrequently identified as appropriations that breached a cost threshold, were also included in the data because they are components of the program acquisition cost.

The following definitions are from the Defense Acquisition University (DAU) Glossary and the DAMIR SAR Data Entry Instructions.

1. Acquisition Procurement Unit Cost (APUC)

APUC is the unit cost that equals the program acquisition cost (the sum of all procurement funds) divided by the total number of fully configured end items to be procured. For unit cost reporting and APB breach purposes, the APUC is calculated in Base-Year dollars (DAMIR 2011, 9–11). Base-year dollars are calculated by using the currently approved acquisition program baseline (APB).[7]

2. Program Acquisition Unit Cost (PAUC)

PAUC is the unit cost that equals the total program acquisition cost (as previously defined) divided by the program acquisition quantity (i.e., the total number of fully configured end items). For unit cost reporting and APB breach purposes, the PAUC is calculated in Base-Year dollars (DAMIR 2011). Base-year dollars are calculated by using the currently approved APB.

[7] The acquisition program baseline (APB) is the baseline that reflects the threshold and objective values for the minimum number of cost, schedule, and performance attributes that describe the program over its life cycle (Defense Acquisition University 2011b). In the event of a cost, schedule or performance objective breach, the APB can be revised; this is called "rebaselining" the MDAP. The initial APB is referred to as the "original" baseline and for a rebaselined program the revised APB is called the "current" baseline. More information about the rebaselining process can be found in Department of Defense Instruction 5000.02, Enclosure 4, Table 6.

3. Procurement

Procurement appropriations fund those acquisition programs that have been approved for production (to include Low-Rate Initial Production (LRIP) of acquisition objective quantities), and all costs integral and necessary to deliver a useful end item intended for operational use or inventory upon delivery (Defense Acquisition University 2011b).

4. Research, Development, Testing and Evaluation (RDT&E)

RDT&E appropriations fund the efforts performed by contractors and government activities required for the Research and Development (R&D) of equipment, material, computer application software, and their Test and Evaluation (T&E) including Initial Operational Test and Evaluation (IOT&E) and Live Fire Test and Evaluation (LFT&E). RDT&E also funds the operation of dedicated R&D installation activities for the conduct of R&D programs (Defense Acquisition University 2011b).

5. Military Construction (MILCON)

MILCON appropriations fund major projects such as bases, schools, missile storage facilities, maintenance facilities, medical/dental clinics, libraries, and military family housing (Defense Acquisition University 2011b). Military construction costs will include only those projects that directly support and are uniquely identified with the subject program (DAMIR 2011).

6. Acquisition Operations and Maintenance (O&M)

Acquisition O & M appropriations fund expenses such as civilian salaries, travel, minor construction projects, operating military forces, training and education, depot maintenance, stock funds, and base operations support (Defense Acquisition University 2011b). Acquisition-related operation and maintenance costs may include acquisition costs which, in special cases, have been funded by operation and maintenance (DAMIR 2011).

B. REPORTING COST BREACHES IN DOD

As previously mentioned, the Selected Acquisition Report (SAR) provides a status update of MDAP cost, schedule and performance information to Congress. The document contains 18 sections which provide extensive details with which decision makers can make informed recommendations for the future of the program. In 1969, the SAR was used to provide periodic updates to the Senate Armed Services Committee. Beginning in 1975, SARs were required to be submitted to Congress in order to keep Congress informed of the status of MDAPs (DAMIR 2011). In the 1980s, more federal legislation was introduced to increase visibility into DoD programs and control cost growth. More discussion about the DAMIR database and SARs is contained in Appendix B.

The Nunn-McCurdy amendment (Title 10 U.S.C. § 2433 2006) to the Department of Defense Authorization Act of 1982 established congressional oversight of MDAPs that experienced cost growth above certain thresholds. The perceived effectiveness of the Nunn-McCurdy amendment led to it becoming a permanent requirement since 1983 in the Department of Defense Authorization Acts (Blickstein et al. 2011, 12). Nunn-McCurdy legislation is the current federal law used to control MDAP cost growth. There have been changes to the Nunn-McCurdy Act over the years, most notably in FY 2006 and FY 2009. In 2006, the original baseline estimate was established as a threshold for measuring cost growth. This prevents a program from rebaselining to avoid a Nunn-McCurdy cost threshold breach. In 2009, Congress endorsed a requirement that any program with a critical breach (defined below) is presumed terminated unless that program has been certified by the Secretary of Defense. More information about MDAP certification requirements can be found in Public Law 111–23, "Weapon Systems Acquisition Reform Act of 2009," May 22, 2009; DoDI 5000.02; and Defense Acquisition Guidebook, Chapter 10.

The determination to use the original baseline or current baseline cost estimate for a program resides in whether the MDAP has been officially rebaselined. Early in the acquisition phase when the "original" or baseline cost estimate for an MDAP—also known as the APB—is established there may be a considerable amount of uncertainty about future project requirements. The uncertainty about various project requirements may result in a program exceeding or "breaching" its original cost estimate. A cost threshold breach is considered to occur when any program cost expenditures exceed the APB. For the purposes of this report, a cost breach is considered greater than or equal to 10% above the APB. Cost breaches that are greater than or equal to 15% above the APB are classified as Nunn-McCurdy cost breaches and have special reporting requirements that are not applicable to cost breaches which do not cross the Nunn-McCurdy threshold.

The Nunn-McCurdy mandate requires reporting of specified cost information and states that "a Nunn-McCurdy breach is any increase in the Current Estimate (CE) of the Program Acquisition Unit Cost (PAUC) objective or Average Procurement Unit Cost (APUC) objective of 15% or more compared to the currently approved [acquisition program baseline] APB, or 30% or more compared to the original APB" (DAMIR 2011). Furthermore, an increase of 15% or more against the current APB objective, or 30% or more against the original APB objective is a "significant" Nunn-McCurdy breach, and an increase of 25% or more against the current APB or an increase of 50% or more against the original APB or revised original APB is a "critical" Nunn-McCurdy breach. The type of cost threshold breach and the APB baseline that it is compared against is shown in Table 1. The APB, established by DoD components and approved by the Milestone Decision Authority, is the baseline cost estimate.

	APB Breach (RDT&E, Procurement, MILCON, O&M)	Nunn-McCurdy "Significant" Breach	Nunn-McCurdy "Critical" Breach
Current Baseline Estimate	10%	+15%	+25%
Original Baseline Estimate	N/A	+30%	+50%

Table 1. Nunn-McCurdy Cost Breach Thresholds

Nunn-McCurdy cost threshold breaches, or cost overruns, are based on original cost estimates for PAUC and APUC at project completion and in the case of a program which has rebaselined, cost threshold breaches are also based on the current (i.e., rebaselined) cost estimate for PAUC and APUC at project completion. To better understand cost overrun calculations, Figure 1 illustrates how the DoD uses earned value management (EVM) to combine "government management requirements and industry best practices to ensure the total integration of cost, schedule, and work scope aspects of contracts" (Defense Acquisition University 2011a, 43–44). For more information about EVM, view the EVM Implementation Guide: http://www.acq.osd.mil/evm/.

Figure 1 shows the total allocated budget of the contract, which is the sum of all of the budgets for work on a contract and the management reserve, a budget which is withheld by the program manager for risk management purposes. The budgeted cost of work performed (BCWP), budgeted cost of work currently scheduled (BCWS) and actual cost of work performed (ACWP) for a contract are the three curved lines in the figure. The BCWP represents the sum total cost of the work packages that are open or completed for a specified amount of time and the BCWS represents the sum total cost of the work that was budgeted for completion within a specified amount of time. The BCWS line is also the contract's performance measurement baseline (PMB) and represents the contract's overall time-phased budget plan. The ACWP is the sum of actual costs that have been incurred to accomplish the work performed within a specified amount of time.

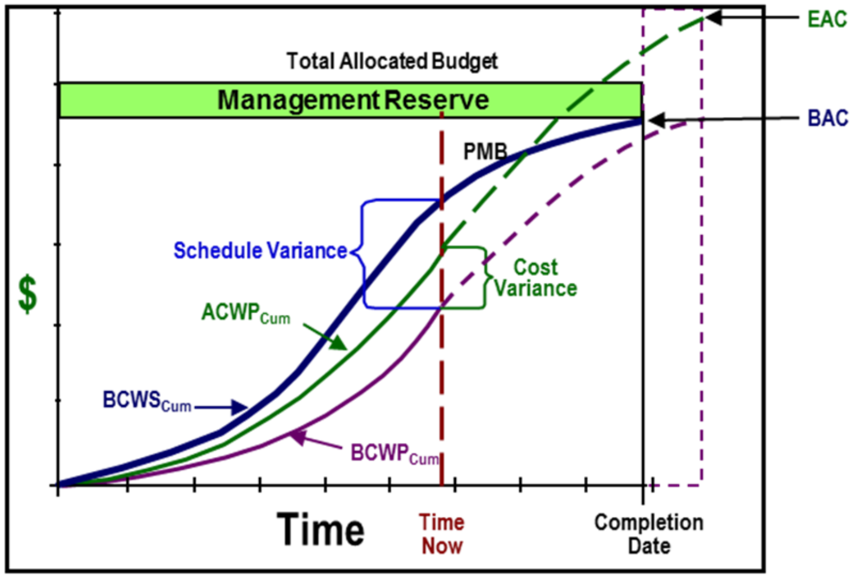

Figure 1. Earned Value Management (From Defense Acquisition University 2012)

The Estimate at Completion (EAC) is the sum of the ACWP and the estimate to completion (ETC) for the remaining work. The ETC can be calculated using previously defined terms, the cost performance index (CPI) and the schedule performance index (SPI). The CPI is calculated by dividing BCWP by ACWP and is a measure of cost efficiency. The SPI is calculated by dividing BCWP by BCWS and is a measure of schedule efficiency. The formula for calculating ETC is:

$$ETC = (BAC - BCWP) / (CPI * SPI) \tag{2.1}$$

When the EAC, a cost estimate for the entire contract, is a higher cost than the Budget at Completion (BAC), the established baseline cost estimate of the contract, a cost overrun is projected. At "Time Now" in Figure 1 the contract is not performing as well as it was predicted to perform. The cost for ACWP exceeds the cost for BCWP, thus creating a negative cost variance and driving the EAC above the BAC. Conversely, if the EAC is less than the BAC a positive cost variance is created and a cost underrun is projected since the contract is not expected to expend the entire allotted budget. Prior to project completion, to calculate the expected cost overrun the current cost estimate must be revised to incorporate ACWP costs and requirements modifications to the existing contract. This revised EAC is then compared to the BAC, the acquisition program baseline (APB, as explained earlier in this chapter) acquisition cost estimate for the contract. The exact percentage of the cost overrun, based on the budget that was established at the APB, can be calculated using the following equation:

$$\% \text{ Cost Overrun} = \left[\frac{\text{EAC}}{\text{BAC}} \text{X}100 \right] - 100 \tag{2.2}$$

Figure 1 also illustrates the cost and schedule overruns for a contract or series of contracts at project completion. At "Completion Date" the contract should be complete, however the schedule variance (the difference between BCWP and BCWS) which often accompanies cost overruns causes the projected date to slip to the right-most dashed line. At this revised completion date, the cost difference between ACWP (no longer EAC because work is complete) and BAC is determined and this delta defines the size of the cost overrun. All of the scheduled work has been performed so BCWS will equal BCWP.[8] The cost overrun calculation can be made using a similar formula:

$$\% \text{ Cost Overrun} = \left[\frac{\text{ACWP}}{\text{BAC}} \text{ X}100 \right] - 100 \tag{2.3}$$

Having considered the categories of cost breaches for MDAPs, as well as exactly how cost breaches are calculated, it is necessary to understand where the cost breach information resides for DoD MDAPs. A single-source document streamlines the process for quickly identifying cost threshold breaches for MDAPs: the selected acquisition report (SAR).

C. SELECTED ACQUISITION REPORTS (SAR)

The Defense Acquisition Management Information Retrieval (DAMIR) system provides electronic Selected Acquisition Reports (SARs) in PDF format for active and inactive MDAPs. SARs contain threshold breach data and a brief explanation delineating the cause of the cost breach. A snapshot of the "Threshold Breaches" section (Table 2) of

[8] In many instances, contracts exhibit a relation between cost and schedule performance. For example, program managers may increase the man-hours allocation of a project in order to meet a schedule deadline. An increase in man-hours allocation, and particularly if the work effort qualifies as overtime pay, may cause project costs to increase.

the SAR provides this information at a glance. The SAR is a single report which contains details of critical parameters of an MDAP or major automated information system (MAIS), to include: the responsible office, threshold breaches, schedule, performance, current contracts and cost details. SARs are required to be submitted on an annual basis and in accordance with the SAR Data Entry instruction quarterly SARs are sometimes required.

Threshold Breaches

APB Breaches		
Schedule		☐
Performance		☐
Cost	RDT&E	☐
	Procurement	☐
	MILCON	☐
	Acq O&M	☐
Unit Cost	PAUC	☐
	APUC	☐
Nunn-McCurdy Breaches		
Current UCR Baseline		
	PAUC	None
	APUC	None
Original UCR Baseline		
	PAUC	None
	APUC	None

Table 2. Threshold Breaches Report from SAR

SARs provide a snapshot of overall MDAP performance and not individual contract performance. For SARs which list a single contract, it is simple to deduce that the information reported in the SAR is the product of the listed contract. However, MDAPs typically require several contracts to be executed, often concurrently, and in many instances multiple contracts are listed on a single SAR. The current contract section of the SAR only includes "the six largest, currently active contracts (excluding subcontracts) that exceed $40 million in Then-Year dollars" (DAMIR 2011). Given that the standard user has limited database permissions and access, the granularity required to determine specific contract performance within an MDAP cannot always be achieved. This means that for MDAPs listing more than one contract in a SAR, if there is a threshold breach it is often difficult to determine which contract(s) caused the threshold breech. On occasion, however, contract notes and comments will provide amplifying information about which contract(s) caused the threshold breach.

To more accurately determine which contracts were responsible for threshold breaches, MDAPs which listed only one contract in the "Contracts" section of the SAR were selected. To further simplify the contract selection process, most programs which featured contracts with "effort numbers" were excluded. The difficulty with the effort numbers is that they complicate contract correlation across databases. For one contract, the effort number in DAMIR does not always accurately correspond to the contract effort number in the DCARC database.

Per the promulgated guidance, "SAR termination will be considered when 90% of expected program deliveries or 90% of planned acquisition expenditures have been made, or when Selected Acquisition Reporting criteria are no longer met" (DAMIR 2011). Therefore, the active MDAPs found in DAMIR are between the beginning of the Engineering and Manufacturing Development phase (Milestone B) and 90% complete. Inactive MDAPs that are complete or >90% complete are no longer required to submit SARs. There are many instances where the final SAR for an MDAP indicates that the program is >90% complete, but not 100% complete. The use of data which may only be 90% complete is presumed acceptable based on the following assumptions:

- 90% of delivered product probably accounts for more than 90% of expenditures.
- Experience indicates that after 90% of the budget has been expended, the remaining 10% of the expenditures have already been committed.

SARs provide relatively high-level contract cost information. For this reason, it was decided that DAMIR would be used solely for the threshold breach data contained in the SARs. The program cost data found in the DD Form 1921 (Cost Data Summary Report, CDSR) provided in the Defense Cost and Resource Center (DCARC) database contains significantly more contract detail. DCARC, an entity of the Office of the Secretary of Defense Cost Assessment and Program Evaluation (OSD CAPE) organization, collects current and historical cost and resource data for MDAPs and MAISs. This cost and resource data is used by government cost analysts to develop cost estimates for government programs (Cost Assessment and Program Evaluation 2013b).

While it is normally not possible to determine system engineering and program management costs from an MDAP SAR, the work breakdown structure (WBS) format of the CDSR makes obtaining this information simple. The data extracted from the MDAP SARs and included in this report is located in Appendix D.

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III. SYSTEMS ENGINEERING AND PROGRAM MANAGEMENT (SE/PM) COST RATIO

This chapter briefly explores transaction cost economics in order to introduce the independent variable, the systems engineering/program management (SE/PM) cost ratio. After explaining how the SE/PM cost ratio is calculated, the source of the raw data that is needed to make the calculations, the Cost Data Summary Report (CDSR) (located in the Defense Automated Cost Information System [DACIMS]), is discussed.

A. TRANSACTION COSTS

Transaction cost economics (TCE) describes the economic theory behind cost analysis performed by an institution in making the decision of whether or not to participate in a market and ultimately incur or avoid expenses. It is generally accepted in the economics community that there are three primary categories of transaction costs: search and information costs; bargaining and decision costs; and policing and enforcement costs (Johnson 2005). To illustrate these cost categories, consider the non-monetary exchanges which occur during the marketing and purchase of a home. The prospective homeowners are working with a realtor to find an acceptable home based on its physical location, size and other intrinsic characteristics (search and information costs). The prospective homeowners will then negotiate between their realtor and the sellers' realtor to determine a purchasing price for the home (bargaining and decision costs). Last, if the home was purchased using money that was borrowed from a mortgage lender, the mortgage company will ensure that the buyers are upholding their end of the agreement by paying the monthly mortgage bill (policing and enforcement costs). Clearly, there is a real (time and effort) cost associated with these three types of transaction costs, albeit difficult to quantify. Firms and corporations consider TCE, if not by name then by practice, to guide their decision to outsource or vertically integrate a service or product which they receive.

The previous paragraph establishes that transaction costs are associated with "source selection, periodic competition and renegotiation, contract negotiation and management, performance measuring and monitoring and dispute resolutions" (Angelis et al. 2008). Although they are not available directly in standard databases, one way to estimate them is by using SE/PM costs. (The importance of those costs in any given program could then be estimated with the fraction of total costs allocated to SE/PM.) As defined in MIL-STD-881C, the combined definitions of systems engineering costs[9] and program management costs[10] are representative of transaction costs and therefore make SE/PM costs a logical proxy for transaction costs.

The SE/PM cost ratio for a program (the ratio of SE/PM costs divided by total program costs as shown in Equation 3.1), specifies the proportion of total program costs that are dedicated to managing, integrating and directing the program:

$$\text{SE / PM Cost Ratio} = \frac{\text{SE / PM Costs}}{\text{Total Cost}} \tag{3.1}$$

This report hypothesizes that a higher SE/PM cost ratio is predictive of future cost threshold breaches. The higher the SE/PM cost ratio then the more risky a transaction is considered—the converse is also implied. Categorizing a SE/PM cost ratio as high or low is a judgment call. There does not appear to be a directed standard or normal-practice SE/PM cost ratio definition across MDAPs. One reason that the SE/PM cost ratios may vary is due to the type of weapon system. Another reason SE/PM cost ratios differ between MDAPs, and sometimes across contracts within the same MDAPs, is due to subjective interpretations among contractors (and program managers) about the definition of SE/PM costs and non-uniform standards regarding which costs qualify to be categorized as SE/PM costs (Stem, Boito and Younossi 2006).

The SE/PM cost values used in this thesis are extracted from the WBS line item values for "To Date" SE/PM Cost and EAC SE/PM cost which are listed on the Cost Data Summary Report (CDSR), DD Form 1921. The "To Date" SE/PM cost is the sum of

[9] Systems engineering costs are the technical and management efforts of directing and controlling a totally integrated engineering effort of a system or program (Department of Defense 2011, 221).

[10] Program management costs are costs associated with the business and administrative planning, organizing, directing, coordinating, controlling, and approval actions designated to accomplish overall program objectives, which are not associated with specific hardware elements and are not included in systems engineering (Department of Defense 2011, 222).

recurring and non-recurring costs for the SE/PM WBS line item as of the date of the WBS report. The EAC SE/PM cost is the projected SE/PM cost at contract completion. The SE/PM costs are inclusive of the total contract costs less the contractor's profit/loss or fees. For clarity, a sample WBS with SE/PM cost ratio calculations is provided in Appendix C.

We analyze SE/PM costs over the life of the MDAP for trends. These trends are significant because the year-to-year increase or decrease in SE/PM costs over the life of the MDAP may be a proactive or reactive measure by MDAP program managers and/or contractors to avoid a threshold breach. Perhaps, an MDAP with a gradually increasing or decreasing SE/PM cost ratio may be indicative of a future cost threshold breach or prevention thereof.

The numerator of the SE/PM cost ratio is the amount of SE/PM cost expenditures and the denominator is MDAP expenditures or total costs. For completeness of analysis, the "To Date" SE/PM and total costs, as well as the EAC SE/PM and total costs are recorded. These four numbers are necessary for the "To Date" SE/PM cost ratio and EAC SE/PM cost ratio calculations, respectively. To illustrate this point, according to our analysis a common sense approach for evaluating the cost performance of MDAP Project X would be to observe its current or "To Date" SE/PM cost ratio and its predicted or EAC SE/PM cost ratio.

B. COST AND SOFTWARE DATA REPORTING

The MDAP database found in the Defense Automated Cost Information System (DACIMS) 3.5 Library and discussed further in Appendix C, electronically lists the recorded contracts for most MDAPs. This Cost and Software Data Reporting (CSDR) library contains folders of active and inactive MDAP contract data sorted by weapons system types. More specifically, contract information within each of these folders includes: the Cost Data Summary Report (CDSR), DD Form 1921; the Functional Cost-Hour Report, DD Form 1921–1; and the Contract Work Breakdown Structure (CWBS) Index and Dictionary among other documents. From the CDSR that is found in DACIMS, we can extract the line item costs that we need for the SE/PM cost ratio calculation. Within a single contract, it is not unusual to find cost data for both the prime vendor who retains the listed contract and subcontracted vendors who support the contract via the prime vendor. To simplify the data collection process, only the cost data provided in the prime contract by the primary vendor is recorded.

A complication to the data collection process occurs when the list of contracts for an MDAP in the DACIMS library does not completely match the list of contracts for the same MDAP in its SAR (Selected Acquisition Report) which is located in the Defense Acquisition Management Information Retrieval (DAMIR) database. For this report, MDAPs with cost threshold breaches are excluded from the data set if the listed contracts are not available in both databases, DACIMS and DAMIR. This is because we need to know the SE/PM cost ratios for the MDAP during the year when the cost threshold breach occurred.

For an MDAP which reports no cost threshold breaches, it is not necessary for all of the listed contracts to be available in both databases. The reason for this is that reliance on the SAR in the DAMIR database assures that no cost breaches occurred. Trusting the SAR allows recording of the SE/PM cost ratios for the contracts that are available in the DACIMS database without fear of excluding a contract SE/PM cost ratio for a year that contained a cost threshold breach—since the SAR confirms that no cost threshold breaches occurred.

In many instances the cost data between DAMIR and DACIMS do not match exactly. Cost data as reported in the SAR is from the perspective of the government representative, or program manager. Cost data contained in the CDSR is reported by the contractor. The difference between government and contractor cost calculations may account for some of the disparity between the two sets of reported cost data. Another source of disparity is that the CDSR and SAR are normally submitted according to different timelines. To lessen accounting inconsistencies, all cost data were retrieved from the DACIMS library (CDSR) and the threshold breech data were obtained solely from the DAMIR database (SAR). Although the accounting figures in the two databases are different, it is assumed that the differences are not so significant that they would change the status (breach or no breach) of any MDAP in regard to its cost threshold breach criteria as reported in the SAR.

The potential for inconsistency in SE/PM cost determination across MDAPs exists due to the individual MDAPs assigning (perhaps implicitly or unintentionally) idiosyncratic definitions for SE/PM costs within their programs. Some insight as to how MDAPs define various contract costs is located in the CWBS Index and Dictionary. The CWBS dictionary contains a description of the technical and cost data for the CWBS elements within the contract. By utilizing the CWBS it is possible, albeit tedious, to ensure to a high degree of confidence that the SE/PM costs between contracts in this study are inclusive of the same types of WBS elements.

Contract data found in the CDSR is given as an initial, interim or final cost summary and is submitted in accordance with the contract CDSR plan as approved by the Office of the Secretary of Defense Deputy Director, Cost Assessment (OSD DDCA). This means that the frequency of submission for cost data documents across different MDAPs varies considerably and that contractor cost data may not be submitted on an annual basis. For this report, to ensure that the cost data contained in the CDSR for an MDAP is relevant to the period covered by the same MDAP's SAR, the reporting periods for the two documents are verified to be within the same calendar year. For example, if an MDAP's CDSR is dated July 2010 and the associated SAR is dated December 2010 then this program and its data are eligible for inclusion in the data set.

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IV. METHODOLOGY OF ANALYSIS FOR COST BREACHES AND SE/PM COST RATIO

This chapter presents the methodology used to test the hypothesis that the likelihood of a major defense acquisition program (MDAP) cost threshold breach may be associated with the transaction costs of the MDAP. While the system engineering/program management (SE/PM) cost ratio is a proxy for transaction costs, interactions between other factors which might be related to cost breaches are acknowledged and explained using an influence diagram. Data were collected for SE/PM cost ratio determinations, as well as for some of the other factors that were presented in the influence diagram. This chapter presents a detailed discussion that describes how all of the data were arranged for use in the statistic models. Accordingly, an explanation of the ordinary least squares (OLS) and logistic regression models which were used for the analysis in this report are included in this chapter.

A. HYPOTHESIS

Numerous reports (e.g., Bolten et al. 2008) have studied cost growth in Department of Defense (DoD) programs, yet research that seeks to establish a potential correlation between the SE/PM cost ratio of an MDAP and the occurrence of a cost breach is limited (Angelis et al. 2008). Is a high SE/PM cost ratio associated with an acquisition program baseline (APB) or Nunn-McCurdy breach? What is considered a high SE/PM ratio? A recent RAND study established that MDAP SE/PM costs vary between programs depending on the program type.[11] For instance, the average SE/PM costs for aircraft development programs are different from the average SE/PM costs of weapons programs.

This report seeks to determine the nature of any potential relationship between transaction costs (using the SE/PM cost ratio as a proxy) and the likelihood of cost breaches experienced by a program. The hypothesis is that programs with higher SE/PM

[11] SE/PM cost is variable between MDAPs because program managers are idiosyncratic with what is included in SE/PM costs. There is no generally accepted standard of what qualifies as SE/PM costs, although it is defined in MIL-STD-881C (October 2011) (Stem, Boito and Younossi 2006).

cost ratios are more likely to experience cost breaches than programs with lower SE/PM cost ratios. This is based on the assumption that higher SE/PM cost ratios are related to riskier contractual relationships since more time, effort and resources are expended to meet performance and schedule deadlines when compared to less risky contracts. Programs with higher transaction costs may experience more cost breaches as a result of those transaction costs not being accounted for in the original cost estimate.

The influence diagram in Figure 2 describes the interactions between factors which may be associated with the occurrence of a cost breach. There are many other variables which affect cost breaches, but the variables identified in this influence diagram (i.e., SE/PM cost ratio, program maturity and contract type) were selected because they can be represented with the data collected. Beginning with the maturity of the program, the maturity variable has quotation marks because "maturity" means different things to different readers. While in this report "maturity" is defined as the time in years since program initiation or Milestone B, many will think first about technology readiness levels (TRLs). Program managers and contractors work together to manage away risk and complexity as the program ages. This process is captured by Figure 2 and is later discussed. Concerning the risk and complexity of the MDAP, the program managers and contractors can only state educated opinions and informed assumptions to guide them in the negotiations for an appropriate contract type. In some cases, the risk associated with the complexity of a new technology may result in a cost overrun. In other instances, perhaps transaction costs associated with managing the MDAP contracts and business negotiations contribute to cost overruns and cost breaches. Because transaction costs are difficult to quantify, the SE/PM cost ratio can be used as a proxy to help understand the contribution of transactions costs to a program's cost overruns and subsequently the probability of the program having a cost breach. Of course not all cost overruns are considered cost breaches. Current estimates which exceed the estimated cost of a program by any amount are considered cost overrun situations. Cost breaches result when the amount of the cost overrun exceeds certain parameters defined by regulation. In this thesis, a default value of 10% cost overrun constitutes the cost breach threshold. Finally, the dashed lines in Figure 2 represent factors that one cannot observe or does not know how to observe and must be dealt with qualitatively or by using proxies. The solid lines represent factors that can be quantitatively evaluated.

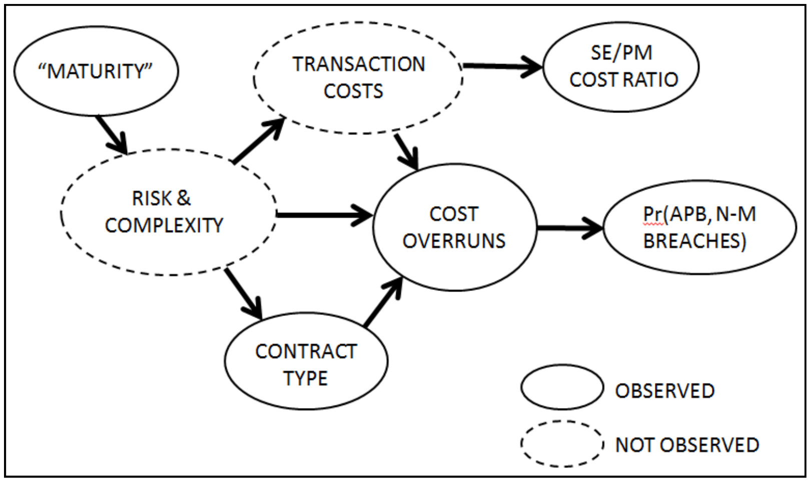

Figure 2. Influence Diagram

There are two types of cost breaches: APB and Nunn-McCurdy breaches. In order for a program to incur an APB breach or Nunn-McCurdy breach, currently estimated program expenditures must be greater than the APB estimate at completion by at least 10% or 15%, respectively. (Cost breaches are discussed in detail in Chapter II, Section B.) The influence diagram shows that not all cost overruns are cost breaches by associating a probability with APB or Nunn-McCurdy breaches. The desire to determine the probability of a binary outcome (breach or no breach) occurring in MDAPs led to the decision to use logistic regression (logit) to model and analyze the data.

This report takes steps toward developing a logistic regression model which program managers may be able to utilize to determine whether their MDAP is in jeopardy of incurring a cost threshold breach. According to this model, program managers will be able to estimate the probability of their program incurring an APB or Nunn-McCurdy breach based on the SE/PM cost ratio which their program maintains. Three models were used to assess the impact of an increase in SE/PM cost ratio on the likelihood of a program experiencing an APB or Nunn-McCurdy breach: a pooled OLS regression, a fixed effects model and a population averaged model.

The null hypothesis of this research states that better incorporation of transaction costs into cost estimates will not significantly affect the ability of an MDAP to operate within its approved financial constraints as measured by cost breaches.

B. DATA

The cost data for 32 MDAPs were collected to determine the presence of any correlation between MDAP cost breaches and transaction costs. The MDAPs were not randomly selected, but instead selected based on the availability of relevant data from the two databases used, Defense Acquisition Management Information Retrieval (DAMIR) and Defense Cost and Resource Center (DCARC). Cost threshold breach information, categorized by the cost appropriation that sustained the cost breach, was available from the Selected Acquisition Report (SAR) in the DAMIR database. At a minimum, the MDAP SARs were generated annually as a means for the program manager to provide a status report to Congress. The line item cost inputs for calculating the "to date" and EAC SE/PM cost ratios were obtained from the Cost Data Summary Reports (CDSRs) found in the Defense Automated Cost Information System (DACIMS) library located within the DCARC database. The 32 MDAPs researched represent the Departments of the Air Force, Army, and Navy, plus Joint programs.

The MDAP data were collected and organized within a data table by dependent and independent variables across a time series for each MDAP (see Appendix D for a list of the MDAPs used in this research). Any type of cost breach, APB cost breach or Nunn-McCurdy cost breach, is considered the binary-outcome dependent variable in this analysis: cost breach or no cost breach. There are three independent or explanatory variables that were included in the analysis for this report: EAC SE/PM cost ratio, time since program initiation and program contract type. While the exact nature of the relationship between cost threshold breaches and these explanatory variables is unknown, it is reasonable to suppose that the explanatory variables influence the cost performance of the MDAPs in some manner.

This research uses binary, clustered and panel data. From the sample provided in Table 3, the binary nature of the data is shown to pertain to the dependent variable "Cost

Breach." In simple terms, the program either sustained an APB or Nunn-McCurdy breach during a specific calendar year or it did not. The clustered nature of the data describes the various categories of program types that the data represents. For example, in Table 3 the MDAP A program may be categorized as a ship building program and the MDAP B program may be categorized as an aircraft development program. This is of particular importance because the average SE/PM cost ratio is variable between program categories and this grouping must be accounted for in any statistical analysis.

Program	Program Number	Contract Year	EAC SE/PM	APB Cost Breach? (0 - no, 1 - yes)	N-M Cost breach? (0 - no, 1 - yes)	"Maturity" (years)	Contract Type (0 - Fixed, 1 - Cost)
MDAP A	20	2005	0.0441	0	0	5	1
MDAP A	20	2006	0.0318	0	0	6	1
MDAP B	21	2007	0.0144	0	0	11	0
MDAP B	21	2009	0.0641	1	0	13	0
MDAP B	21	2010	0.1626	0	0	14	0
MDAP B	21	2011	0.1342	1	1	15	0
MDAP C	22	2000	0.0292	1	0	7	0

Table 3. Sample Data Set

The importance of accounting for clustering is noted in Logistic Regression Using the SAS System (Allison 2001, 180):

- Ignoring clustering and treating each observation as independent may cause the calculated standard errors to be underestimated and the test statistics to be overestimated.
- Applying conventional logit analysis, which will be explained in Section C of this chapter, to clustered data will produce standard errors that may be larger than those standard errors produced by other analysis methods.
- Clustered data can be corrected for biases that may occur in any application of binary regression, i.e., a particular logit analysis method can correct for bias due to omitted explanatory variables.

Last, the dataset in Table 3 shows observations of multiple independent variables that have been collected for a program over a time series (measured in years) and in statistics this type of data collection is known as panel data.

Program work breakdown structure (WBS) line item costs for SE/PM were obtained from cost data summary reports (CDSR, DD Form 1921) found in the DCARC database. The SE/PM cost ratios calculated serve as the proxy for transaction costs. The "to date" SE/PM cost ratios were calculated by dividing the "to date" SE/PM cost by the "to date" total cost of the program. Similarly, the estimate at completion (EAC) SE/PM cost ratios were calculated by dividing the EAC SE/PM cost by the EAC total cost of the program. SE/PM cost data ratio calculations were recorded by year for each program, as available. During the development of this report, it was decided that "to date" SE/PM cost ratios provided extraneous information and would not be included in data analysis since MDAP cost breaches are based on EAC cost projections and not "to date" cost expenditures.

In this report, program "maturity" describes the time that has elapsed since program initiation (or Milestone B, the entry point into the Engineering and Manufacturing Development phase). The concept of maturity may seem quite simple; however, this definition also implies attainment of the DoD requirements for an MDAP to accomplish Milestone B approval, namely that the design and technology utilized in the project are mature.[12] Using the DoD Milestone B requirements to define maturity ensures that each program analyzed in this report is assessed beginning with a comparatively equitable baseline. Presumably, as time progresses, a project's contracts should have a smaller likelihood of incurring a cost breach for each successive year after program initiation because there is more available information about the project and the realm of the unknown is decreasing. The increase in system or program information and the corresponding reduction in uncertainty are represented by the uncertainty-information

[12] Milestone B approval authorizes an MDAP to enter the Engineering and Manufacturing Development phase of the acquisition process. Statutory requirements for MDAPs to achieve Milestone B approval are found in Title 10 U.S.C. § 2366b. These requirements include that the program is certified by the milestone decision authority to be affordable, fully funded through the Future Years Defense Program (FYDP) and that the cost and schedule estimates are reasonable.

tradeoff as a function of program maturity as shown in Figure 3 (After Yoe 2000, 2). This figure suggests that the greatest uncertainty in a cost estimate occurs in the earlier stages of a program when there are more future unknowns as compared to the later stages of a program.

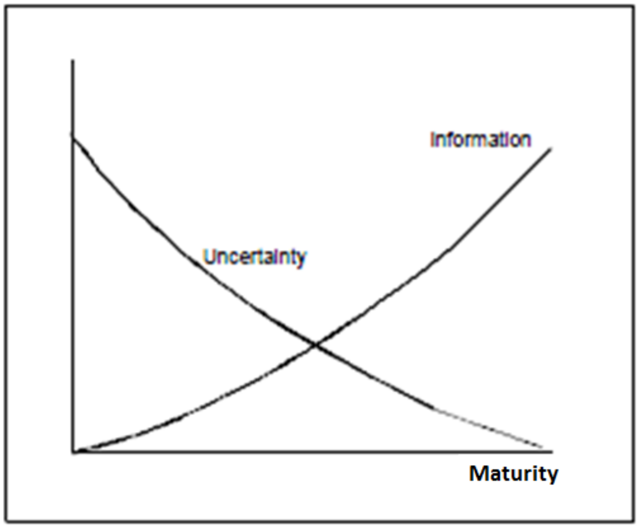

Figure 3. Uncertainty and Information as a Function of Maturity.
(After Yoe 2000, 2)

The time since program initiation at Milestone B is obtained from the Selected Acquisition Report (SAR) that is promulgated annually in December by the MDAP program office and an extensive listing of the active and inactive SARs for all DoD programs (Air Force, Army, Joint, Navy) can be accessed via the Defense Acquisition Management Information Retrieval (DAMIR) database. The time elapsed since Milestone B for a contract may not always accurately represent the amount of time that an MDAP has been in existence. For instance, the AIM-9 Sidewinder first entered service the 1950s (Wikipedia 2013), but many of the later variants of the AIM-9 were developed using contracts from more recent years, such as the AIM-9X program which began in 1996 (MacKenzie 1997). In instances such as the AIM-9X program, the program initiation date for the specific variant contracted was utilized to determine the maturity of the program.

Program contract type is obtained from the contracts (CDSRs) which are found in the DCARC database. Programs are noted as having either firm fixed price type contracts or cost-plus type contracts. It is presumed that riskier programs will have cost-plus contracts since contractors will be hesitant to enter into firm fixed price contracts which require them to meticulously manage the costs of the work in order to earn a profit.[13]

C. APPROACH TO ANALYSIS

Given the nature of the data, a good starting point was to consider a bivariate model to explain cost breaches and transaction costs. Using a standard bivariate regression, one variable would be considered to predict an outcome variable (Acock 2006, 211). In the case of this research, a high value for the independent variable of SE/PM cost ratio may manifest as a possible ex-ante indicator for a cost breach in an MDAP. It has already been established that we are analyzing clustered panel data and that the average SE/PM cost ratios are different between program types. Thus, a single SE/PM cost ratio value that would indicate a cost breach is of no use to a program manager since there is no accounting for the variance across program types. For example, the overall SE/PM cost ratio could be a value that is lower than the average SE/PM cost ratio for programs that normally maintain a comparatively high SE/PM cost ratio. Certainly SE/PM cost ratio alone does not indicate that an MDAP will have a cost breach (e.g., Sullivan 2011). While other factors that might impact cost breaches were taken into account, data clustering has not yet been taken into consideration.

A multiple regression model is the next logical model that may be considered. A multiple regression makes sense because it would incorporate input from many predictors or independent variables to predict the outcome variable (Acock 2006, 212). Again, finding a single SE/PM cost ratio value which may indicate an increased likelihood for a breach does not seem like it would be helpful to a program manager since SE/PM cost ratios variables between MDAP types.

[13] A cost plus contract is a type of contract that provides for payment to the contractor of allowable costs incurred in the performance of the contract, to the extent prescribed in the contract. This type of contract establishes an estimate of total cost for the purpose of obligating of funds and establishes a ceiling that the contractor may not exceed without prior approval of the Contracting Officer (CO). A firm fixed price contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. This type of contract places upon the contractor maximum risk and full responsibility for all costs and resulting profit or loss. It provides maximum incentive for the contractor to control costs and imposes a minimum administrative burden on the government (Defense Acquisition University 2011b).

Perhaps instead of finding a single SE/PM cost ratio that would presumably alert program managers to the impending danger of an APB or Nunn-McCurdy cost breach, it would be more helpful to provide program managers with an indication of the risk of incurring a cost breach. A ratio, adjusted to be program-specific, that program managers may reference for their decision making.

In the case of an MDAP cost breach, the outcome variable is binary: breach or no breach. Logistic regression is a type of regression that was designed for binary-outcome dependent variables (Acock 2006, 250). Logistic regression predicts the probability of binary outcomes (breach or no breach). The S-curve seen in Figure 4 indicates the relationship between the linear probability and logit models. In order to fit this model, a logit or maximum likelihood estimation is calculated for each observation. Mathematically, the logit value (Equation 4.1) is the natural logarithm of the odds ratio for a given event to occur (Acock 2006, 256); and the odds ratio is simply the ratio of the event occurring versus the ratio that the event will not occur. Each point on the logistic regression line in Figure 4 represents a logit value which describes the relationship between the dependent and independent variable.

$$\text{Logit} = \ln\left(\text{odds ratio}\right) \tag{4.1}$$

Although the probability of an MDAP crossing a cost threshold is not linearly related to the SE/PM cost ratio, the logit is and therefore the predicted logit of a cost breach occurring is the statistical equivalent to the predicted probability of a cost breach occurring (Acock 2006, 253).

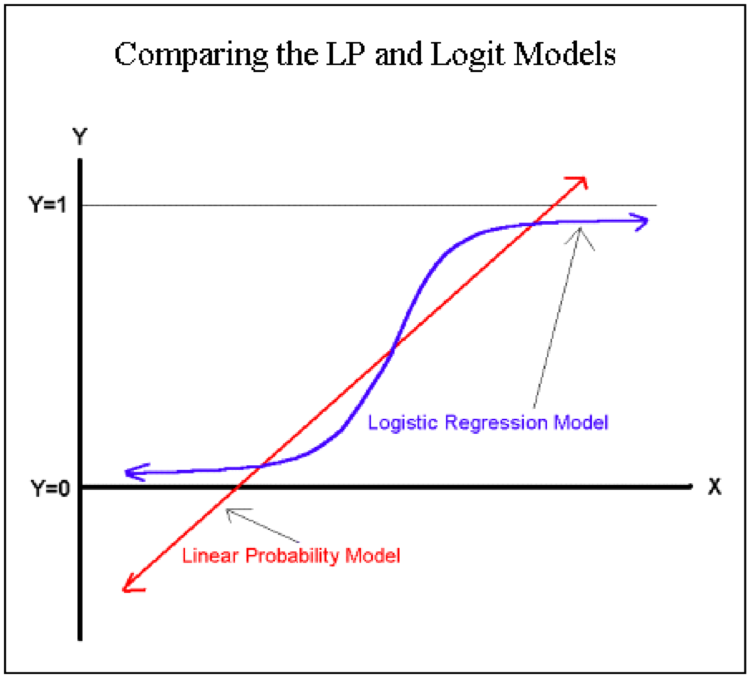

Figure 4. Linear Probability versus Logit Model
(From http://www.appstate.edu/~whiteheadjc/service/logit/logit.gif)

In this study, the pooled OLS regression serves as the baseline model. The data is considered "pooled" because it uses all of the independent data observations. Unfortunately, while the binary outcome is limited to a maximum probability of 1.0 (100%) and minimum probability of 0.0 (0%), OLS regression is not constrained to these limits. Because it uses linear estimates, OLS regression may result in predicted likelihoods greater than 1.0 or less than 0.0. Additionally, OLS regression assumes that each observation is independent, but we already know that this is not the case with the MDAP data: observations from within the same cluster or program are probably more alike than observations from another cluster. In other words, it is expected that within group outcomes are related differently than the cross-group outcomes. The assumption that each observation is completely independent skews the calculated standard errors for the data. A solution to the problems presented by the OLS regression model is to employ one of several maximum likelihood estimators and panel data techniques.

The second model tested was a fixed effects logistic regression model. The fixed effects or conditional logit model adjusts for bias introduced by omitted explanatory variables within the clusters of data. It controls for characteristics which may cause a cost breach even if those characteristics cannot be measured. The standard logit model is presented in Equation 4.2 (Allison 2001, 181), where P_{it} represents the probability that at a specific time an MDAP breaches a cost threshold, β_{it} is the vector of regression coefficient which represents the association of cost breaches and the explanatory variable to a unit change in the independent variable (SE/PM cost ratio) and x represents the explanatory variable for the respective MDAP.

$$\text{Log}\left(P_{it} \,/\, 1-P_{it}\right) = \beta_{it}\text{x} \tag{4.2}$$

The fixed effects (conditional) logit model, which accounts for dependence of the observations within a group, modifies the basic logit model (Equation 4.3) (Allison 2001, 188). In this equation, α represents a set of fixed constants for each MDAP in the group. This model measures the impact of deviations by the independent variable from the group's (program's) mean. This model can be considered to describe the impact of short run changes, i.e., that a change in the SE/PM cost ratio for an MDAP will change its probability of breaching a cost threshold.

$$\text{Log}\left(P_{it} \,/\, 1-P_{it}\right) = \alpha + \beta_{it}\text{x} \tag{4.3}$$

Finally, the relationship between SE/PM cost ratio and cost breach was modeled using a population averaged logit model. Contrary to the fixed effects method that looks *within* programs for changes in the SE/PM cost ratio, the population averaged method looks *across* programs to measure changes in the SE/PM cost ratio. Therefore, using Equation 4.3 to explain the population averaged logit model, α represents a set of averaged constants for MDAPs across program groups. The population averaged method is most useful for measuring long run effects, i.e., measuring whether programs with high average SE/PM cost ratios are more likely to breach.

D. SUMMARY

A logistic regression model, or a maximum likelihood estimator such as logit which uses the natural logarithm of the odds ratio, is appropriate for this research because it was designed for use with binary-outcome dependent variables. Additionally, a fixed effects logit model will adjust for bias introduced by omitted explanatory variables within the clustered panel data and a population averaged logit model is appropriate for examining across clusters of panel data. Now that the models used in this research have been justified, it is necessary to look at the results that the various logit models provide and the differences between them.

V. INTERPRETATION OF EAC SE/PM COST RATIO ANALYSIS

This chapter contains a detailed analysis of the data and provides an interpretation of the analysis results. This first section contains a general description of the data collected. The next three sections describe the relationship between major defense acquisition program (MDAP) cost breaches and the independent variable and explanatory variables that incrementally expanded the model. These three sections provide equations that model the variables being tested, as well as the results of ordinary least squares (OLS) and logit regression analysis. The chapter concludes with a summary of the most significant data analysis results.

A. OBSERVED MDAP EAC SE/PM COST RATIOS

A visual representation of MDAP cost breaches compared to MDAP estimate at completion (EAC) system engineering/program management (SE/PM) cost ratios is shown in Figure 5. As a reminder, in this report cost threshold breaches are cost overruns which are greater than or equal to the default APB cost breach threshold value of 10%. Therefore, for this model cost breaches include APB cost breaches and Nunn-McCurdy cost breaches, since the Nunn-McCurdy cost breach thresholds are all greater than 10%. More specifically, Figure 6 shows the total number of cost breaches reported by the Selected Acquisition Reports (SAR) that a program has sustained and compares it against the program's average SE/PM cost ratio. There are no discernible patterns in Figure 6, so the data were re-configured to see whether another presentation yielded any patterns or a different interpretation.

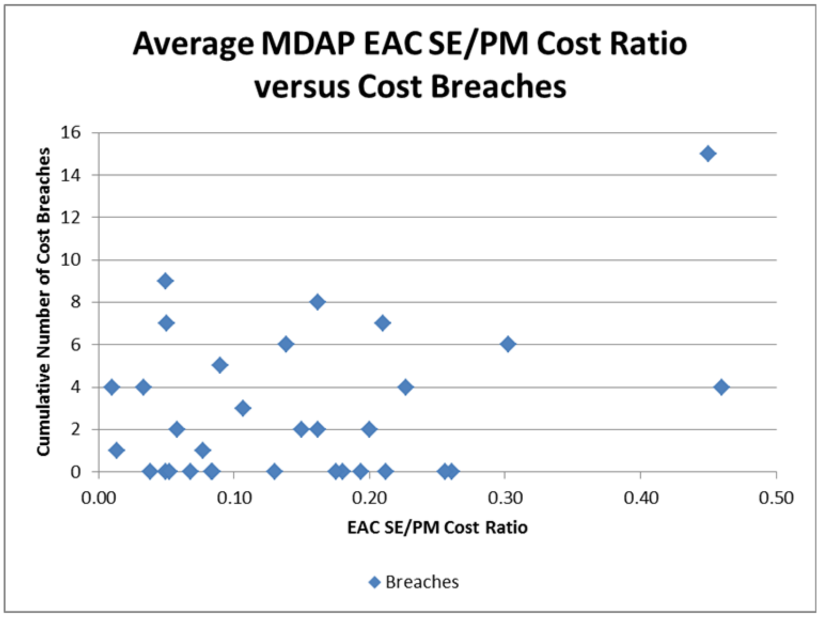

Figure 5. MDAP EAC SE/PM Cost Ratio versus Cost Breaches

Figure 5 is based on the cost threshold breach and corresponding cost data that was available for 32 selected MDAPs since 1998. From this representation of the data, it appears that more than half of the MDAPs maintain an EAC SE/PM cost ratio of 0.20 or less and have experienced less than two cost breaches since 1998. Furthermore, it can be inferred that most of the programs have experienced at least one cost breach and these inferences seems to confirm a recent RAND report which found that most MDAPs actual costs exceeded baseline cost estimates (Arena et al. 2006).[14]

Observations of the MDAP SE/PM cost ratios in this report seem to concur with the RAND study which suggests that trends in SE/PM costs vary across MDAPs (Stem, Boito and Younossi 2006). For this reason, it is challenging to identify relationships between SE/PM costs and cost breaches. The average EAC SE/PM cost ratio for the sample data set of 32 MDAPs is 0.16. This suggests that on average, program managers of the MDAPs studied in this report spent 16% of their budgets on systems engineering and program management activities. Recall that the systems engineering and program management costs are used as proxy measures of the transaction costs required to administer and to manage the MDAP.

[14] For most of the programs reviewed, actual costs exceeded the baseline cost estimate established at Milestone II (program initiation), as measured by the cost growth factor (Arena et al. 2006).

A histogram of the EAC SE/PM cost ratios observed in this study is shown in Figure 6. From this histogram we can observe that while most observed ratios varied between 0.05 and 0.35, there do appear to be two outliers having values of 0.50.

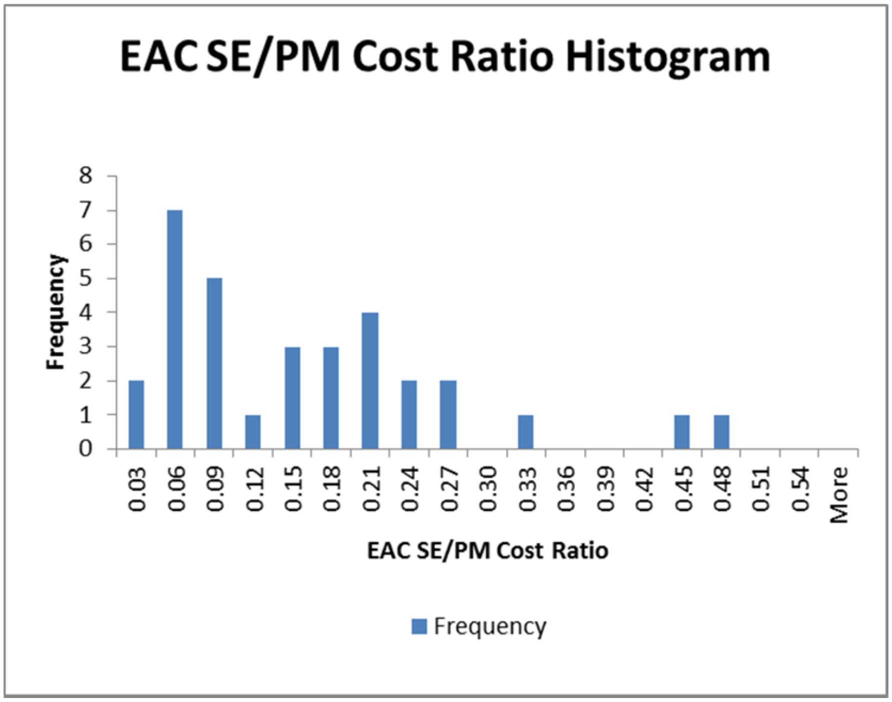

Figure 6. EAC SE/PM Cost Ratio Histogram for MDAPs

We assume for parametric analysis that the variables are normally distributed because one of the underlying assumptions of OLS regression is that the data is normally distributed. A normal probability plot (Figure 7) was used to evaluate the normality of the data. This plot suggests that the data is normally distributed with an r-squared value of 0.85.[15] While this normality will support the use of OLS regression in our analysis, it is not required for logistic regression.

[15] The r-squared value measures the goodness of fit of the data to the trend line shown in Figure 7. In a perfect dataset, the normal probability plot of normally distributed data will be a perfectly straight line with an r-squared statistic of 1.0. The dataset used in this report is confirmed to be normally distributed due to its relatively linear normal probability plot and the r-squared statistic of the trend line being 0.85.

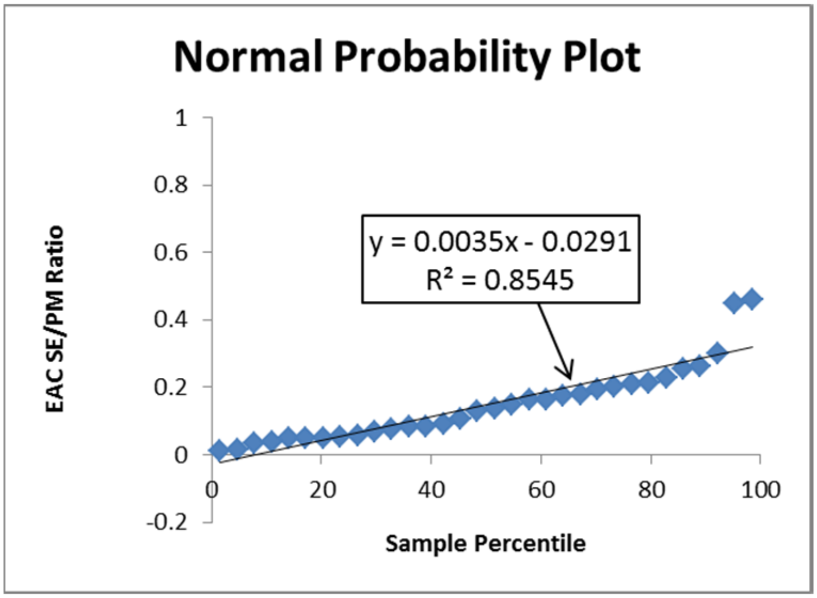

Figure 7. Normal Probability Plot of EAC SE/PM Cost Ratio

In Figure 8, we see MDAP EAC SE/PM cost ratios binned by various numbers of cost threshold breaches for selected MDAPs since 1998. It appears that the information in Figure 8 can plausibly be described by a simple linear regression and this was a primary reason that the linear bivariate and multiple regression models were suggested to model the data, as explained in the previous chapter. If this is a valid correlation, it supports the hypothesis that "programs with higher SE/PM cost ratios will experience more cost overruns than programs with lower SE/PM cost ratios." Armed with this information, it is logical to suspect that the likelihood of a program sustaining a cost threshold breach could be associated with a certain SE/PM cost ratio. The null hypothesis is that the probability of a cost threshold breaches is not associated with the MDAP EAC SE/PM cost ratio and that the model has no explanatory power.

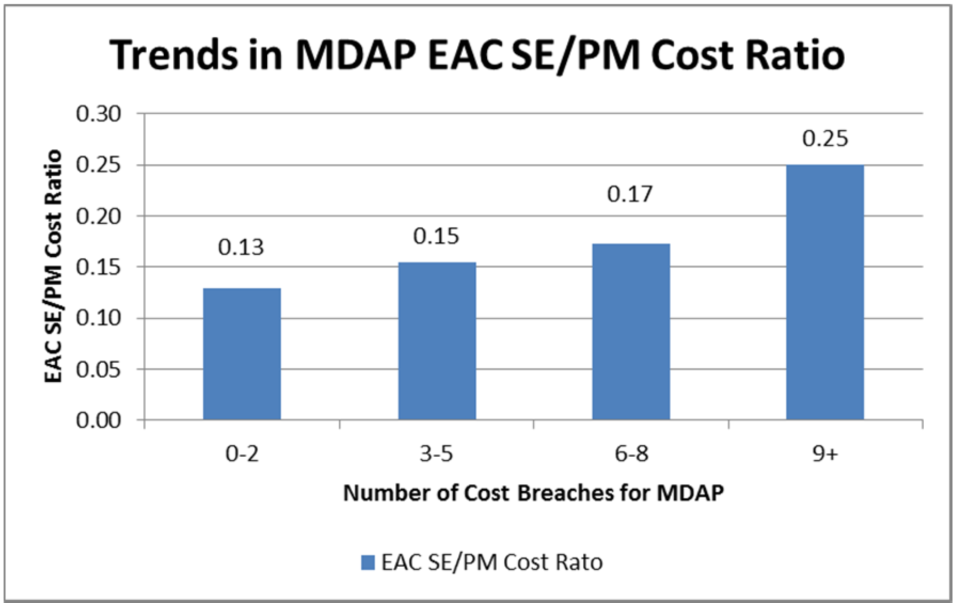

Figure 8. Trends in MDAP SE/PM Cost Ratios

B. COMPARISON OF MDAP COST BREACHES TO SE/PM COST RATIOS

The OLS and logistic regression techniques that were discussed in the previous chapter will be utilized and some of the strengths and weaknesses of these models will be described. The most valuable information obtained from these models is the marginal effects and average marginal effects values. The marginal effects values describe the impact of the independent variable on the dependent variable. For example, if our analysis were to conclude that the average marginal effect of EAC SE/PM cost ratio was 0.95, then the model is stating that a 1.0% change in the independent variable (EAC SE/PM cost ratio) will result in a 0.95% change in the dependent variable (cost breaches). It is important to understand that although correlation may exist between the dependent and independent variable, causation between the two variables cannot be implied.

We will now look at results yielded by the analysis methods that were described in the previous chapter: pooled OLS regression, logit fixed effects regression and logit population averaged regression. In the first series of model runs, the variable being tested for correlation with cost breaches is the EAC SE/PM cost ratio. For the remaining sections of this chapter, it will be helpful to consider the following linear model to explore many variables and cost breaches:

$$Y = \alpha + \beta_0 X_0 + \beta_i X_i.$$

Variations of this linear model will also be helpful for interpreting the statistical tables which are presented in this section. For this linear model, β_o is the regression coefficient that will be associated with the independent variable (EAC SE/PM cost ratio) and β_i is the regression coefficient that will be associated with all other explanatory variables. In general, the regression coefficient (β_i) represents the amount that the dependent variable (Y) and explanatory variable (X_i) can be associated to a unit change in the independent variable EAC SE/PM cost ratio (X_0). The dependent variable, Y, represents the likelihood of a cost breach occurring. The constant (α) represents the value of the probability of a cost breach occurring when there are no explanatory variables (X_i) and EAC SE/PM cost ratio (X_0) is zero (Hutcheson n.d.). Accordingly, for the first series of data tests, the equation for the model being tested is:

$$Y = \alpha + \beta_0 X_0$$

$$X_0 = \text{EAC SE/PM cost ratio}$$

The hypothesis being tested is that the probability of a program sustaining a cost threshold breach is related to the EAC SE/PM cost ratio of the MDAP. The null hypothesis is that there is no relation between the probability of a cost threshold breach and the EAC SE/PM cost ratio and that the model has no explanatory power.

The results of all three of the regression models without considering any other explanatory variables, such as the time since program initiation (Milestone B) or the type of contracts within the program are shown in Table 4. The OLS regression and logit population averaged regression models indicate a positive relationship that is significant at the 5% level ($p = 0.05$) between EAC SE/PM cost ratio and the likelihood of a cost breach occurring. Since we established in the previous chapter that the OLS regression does not adequately model the data and the logit fixed effects (FE) model is not significant, only the logit population averaged (PA) regression results will be further examined.

The marginal effect of the logit population averaged model shows that, based on *across* programs observations, for every unit change in EAC SE/PM, the log odds rise in the probability of a cost breach occurring is 0.80.[16] This means that for every 1% increase or decrease in the EAC SE/PM cost ratio, there is an average increase or decrease of 0.8% in the probability of a program sustaining a cost threshold breach. In logistic regression, the value of the marginal effect is not constant and must be interpreted accordingly. For example, per Table 4 when the EAC SE/PM cost ratio is 0.1 the marginal effect on the likelihood of a cost threshold breach is 0.76. When the EAC SE/PM cost ratio is equal to 0.1, a 1% increase in the EAC SE/PM cost ratio will positively correspond to a 0.76% increase in the likelihood of a cost threshold breach occurring. The remaining results of the model are:

- When the EAC SE/PM cost ratio is 0.2, a 1% change in EAC SE/PM cost ratio positively corresponds to a 0.90% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.3 a 1% change in EAC SE/PM cost ratio positively corresponds to a 0.98% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.4 a 1% change in EAC SE/PM cost ratio positively corresponds to a 1.00% change in the probability of a cost breach occurring.

[16] The logit value is the "log odds" value and is mathematically defined to be the natural logarithm of the odds ratio that a certain event will occur; and the odds ratio is simply the ratio of the event occurring versus the ratio that the event will not occur. Logit modeling is discussed in Chapter IV, Section C "Approach to Analysis."

EQUATION	VARIABLES	OLS Breach (X_o)	Logit-FE Breach (X_o)	Logit-PA Breach (X_o)
	EAC SE/PM Cost Ratio (β_o)	1.097** (0.421)	-9.238 (7.825)	4.006** (2.021)
	Constant (α)	0.143* (0.0789)		-1.473*** (0.454)
	Number of Observations	84	39	84
	R-squared Statistic	0.079		
	Number of Programs	32	11	32

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Average Marginal Effect in PA model is .8

ME @ EAC=0.1 0.76
ME @ EAC=0.2 0.90
ME @ EAC=0.3 0.98
ME @ EAC=0.4 1.00

Table 4. Impact of EAC SE/PM with No Explanatory Variables

In Table 4, the number of observations represents the number of data points that were tested and each data point has a distinct program name and year. The "number of programs" is the number of programs tested in each model. For the OLS model, all of the programs were tested. The r-squared statistic is a "goodness of fit" value for the model to the data points (no such statistic exists for logistic regression). The r-squared value is interpreted to mean that the independent variable, EAC SE/PM cost ratio, explains 7.9% of the variance in this model. It is not surprising that the r-squared statistic is so small and this is a testament that the single variable identified in the model (i.e., EAC SE/PM cost ratio) does not explain most of the variation in the dependent variable. The robust standard error, which is the square root of the estimate of variance for this model, is used instead of the standard error because it is expected to be more accurate when heteroskedasticity and autocorrelation exist. Heteroskedasticity describes the variance in the error terms of the dependent variable as the value of the explanatory variable changes (Barreto and Howland 2006, 508–509). Autocorrelation is the correlation of a variable value with itself across a time series.

It is interesting to note that the logit fixed effects model which looks within programs does not show correlation between EAC SE/PM and cost breaches. This seems to suggest that *within* a program the likelihood of a program incurring a cost threshold breach cannot be associated to the EAC SE/PM cost ratio. This may be because the fixed effect model uses a short term within program analysis from which the change in likelihood for a cost breach occurring cannot be observed. It is also possible that no correlation is noted in the fixed effects model because more explanatory variables are needed to explain the relationship. Nonetheless, we can state that there is no within-program evidence that a change in EAC SE/PM is associated with a change in the likelihood of a cost breach occurring.

The logit population averaged model provides a long term look across programs and yields statistically significant results for associating cost breaches to EAC SE/PM cost ratio. The across programs look can be interpreted as indiscriminately considering all Department of Defense (DoD) MDAPs in the data set, regardless of the program's affiliation with a specific service or weapons type. The results suggest that, in general, the probability of a cost breach occurring is related to the EAC SE/PM cost ratio. That the logit population averaged model and the OLS model both show a statistically significant relationship between EAC SE/PM and cost breaches is interesting; however, as discussed in the previous chapter, the OLS regression does not account for clustered data. That the OLS regression and logit population averaged model are both statistically significant may further support the claim that when considering all MDAPs, any randomly selected program is likely to have correlation between EAC SE/PM cost ratio and the probability of a cost breach.

According to Table 4, the marginal effect of EAC SE/PM cost ratio, as defined in Chapter III, is a value of 0.80 for the population averaged model, for an almost one to one correlation between changes in EAC SE/PM cost ratio and changes in the likelihood of a cost breach. Figure 9 illustrates the relationship between EAC SE/PM cost ratio and cost breaches for the population averaged model. The low p-value for the logit population averaged model ($p < 0.05$) confirms the statistical significance of these results. In other words, we can assume that there is a less than 5% possibility that the results yielded in this study occurred by chance (Thisted 2010). Nonetheless, provided the low r-squared statistic (0.079) we are missing some of the explanatory variables that contribute to the probability a cost breach occurring.

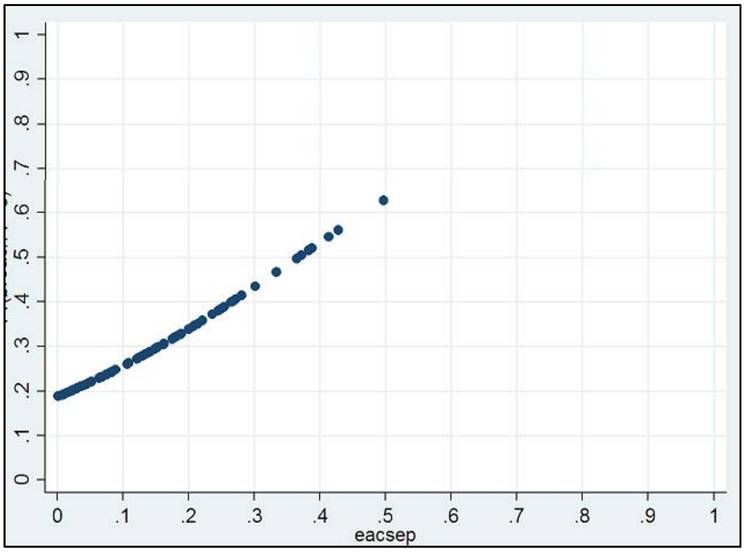

Figure 9. Cost Breach versus SE/PM Logistic Regression S-Curve

Interpretation of the regression s-curve provided (Figure 9) may lead the reader to correctly conclude that an increase or decrease in the EAC SE/PM cost ratio will be associated with a corresponding increase or decrease in the probability of a cost breach occurring. Again, it is necessary to recall that while there may be an association between EAC SE/PM cost ratio and cost breaches, there is no evidence which suggest or supports any claim that the EAC SE/PM is the causal factor for a cost threshold breach.

The analysis suggests that there is a possible relation between SE/PM cost ratio and the likelihood of occurrence of a cost threshold breach. For example, if an MDAP has a SE/PM cost ratio of 0.20 we expect a 30% likelihood of incurring a cost breach. If that same MDAP's SE/PM cost ratio were to increase to 0.40, the analysis suggests a corresponding increase in the probability of a cost breach occurring, to a 60% chance of incurring a cost breach. Notwithstanding, there is no evidence that the EAC SE/PM cost ratio should be considered a causal factor for cost breaches, merely an indicator.

C. COMPARISON OF MDAP COST BREACHES TO SE/PM COST RATIOS AND PROGRAM MATURITY

The logarithm of program maturity, considered in this report to be the length of time (in years) since the requisite program contracts entered Milestone B, was used to expand the model. As discussed in Chapter III, this definition of maturity also incorporates attainment of the DoD requirements for an MDAP to accomplish Milestone B approval, namely that the design and technology utilized in the project are mature. The rationale behind measuring the effect of log maturity against cost breaches is that we expect older programs to have less uncertainty and risk than younger programs. It is presumed that older programs have more experienced managers and more streamlined and efficient processes as compared to a younger program, thus making older programs less likely to sustain a cost breach. Taking the natural log of maturity helps to linearize the relation of maturity to cost breaches in this model. In this section, we will look at the impact of EAC SE/PM cost ratio on the likelihood of a cost breach occurring while including the explanatory variable "Log Maturity," the logarithm of the maturity variable:

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1$$

$$X_0 = \text{EAC SE/PM Cost Ratio}$$

$$X_1 = \text{Log Maturity}$$

The null hypothesis is that there is no relation of cost breaches with EAC SE/PM cost ratio and program maturity as defined in this report. The analysis is modeled by logit fixed effects and logit population averaged models and the resulting impact of the explanatory variable Log Maturity is displayed in Table 5.

VARIABLES	Logit-FE (X_i)	Logit-PA (X_i)
Log Maturity (β_1)	0.429	0.350
	(0.877)	(0.302)
EAC SE/PM Cost Ratio (β_0)	-8.826	4.449**
	(7.897)	(1.907)
Constant (α)		-2.193***
		(0.752)
Number of Observations	39	84
Number of Programs	11	32

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Average marginal effect in PA of Log maturity is 0.7 and EAC SE/PM Cost Ratio is 0.89

ME @ EAC=0.1 0.83
ME @ EAC=0.2 0.99
ME @ EAC=0.3 1.08
ME @ EAC=0.4 1.08

Table 5. Impact of EAC SE/PM with Log Maturity

While the logarithm of the length of the program does not have a statistically significant effect in all of the models, the average marginal effect of Log Maturity in the population averaged logit model is 0.70 and for EAC SE/PM cost ratio the average marginal effect is 0.89. This means that a one unit (1%) change in the Log Maturity of an MDAP equates to a 0.70% change in the likelihood of a cost breach occurring. Similarly, a one unit (1%) change in the EAC SE/PM cost ratio will result in a 0.89% change in the likelihood of an MDAP incurring a cost breach. The remaining results of the model are:

- When the EAC SE/PM cost ratio is 0.1, a 1% change in EAC SE/PM cost ratio positively corresponds to a 0.83% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.2, a 1% change in EAC SE/PM cost ratio positively corresponds to a 0.99% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.3, a 1% change in EAC SE/PM cost ratio positively corresponds to a 1.08% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.4, a 1% change in EAC SE/PM cost ratio positively corresponds to a 1.08% change in the probability of a cost breach occurring.

The practical interpretation of these results may be that SE/PM costs become a larger percentage of the total program costs due to the proactive or reactive actions of the program manager to avoid a cost threshold breach. Thus, there is evidence to suggest that the SE/PM cost ratio may be an indicator of cost troubles.

D. COMPARISON OF MDAP COST BREACHES TO SE/PM COST RATIOS, PROGRAM MATURITY AND CONTRACT TYPE

We will now examine the impact of the type of contract on the likelihood of a cost breach occurring. Contract type was included because it is generally accepted by acquisitions professionals that firm fixed price contracts are frequently negotiated between the government and contractors for less risky programs and cost-plus contracts are negotiated for projects which have greater uncertainty and are perceived to be more risky (Government Accountability Office 2009b). Much of the rationale for associating contract types and projects based on the perceived riskiness of the projects is rooted in the cost sharing and incentives offered by the different contract types.[17] Nonetheless, it seems logical that riskier MDAPs should have cost-plus contracts and experience more cost breaches than their less risky counterparts. The null hypothesis of this analysis is that there is no relation between cost breaches and EAC SE/PM cost ratio, log maturity and MDAP contract type. The linear equation model which analyzes the impact of EAC SE/PM on the likelihood of a cost breach occurring while including the explanatory variables Log Maturity and MDAP contract type is:

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1 + \beta_2 X_2$$

X_0 = EAC SE/PM Cost Ratio

X_1 = Log Maturity

X_2 = Contract Type

For this model, firm-fixed price contracts have β_2=0 and cost-plus contracts have β_2=1.

[17] In a firm fixed-price contract there is not cost sharing between the government and the contractor and the contractor has full responsibility for the performance costs and resulting profit (or loss). In a cost-plus contract, a share ratio based on the contract cost and the contractor's fee (profit) is negotiated so that the contractor has a pre-determined responsibility for the performance costs which will directly affect the fee (profit). In the case of both contract types, incentives may be offered in which the contractor's responsibility for the performance costs and the profit or fee incentives offered are tailored to the uncertainties involved in contract performance (General Services Administration 2005).

VARIABLES	Logit PA (X_i) "Fixed Price" (β_2=0)	Logit PA (X_i) "Cost Plus" (β_2=1)
Log Maturity (β_1)	-0.0967	1.115**
	(0.586)	(0.553)
EAC SE/PM (β_0)	-2.121	5.172*
Cost Ratio	(4.665)	(2.846)
Constant (α)	-0.906	-3.255***
	(1.346)	(1.214)
Number of Observations	37	41
Number of Programs	15	16

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Including ME for the type 1 model only
Average marginal effect in PA of Log maturity is .21, and EACSEP is 1.00

ME @ EAC=0.1 0.94
ME @ EAC=0.2 1.08
ME @ EAC=0.3 1.12
ME @ EAC=0.4 1.07

Table 6. Logistic Regression with Log Maturity and Contract Type

Noting the results summarized in Table 6 and considering the independent and explanatory variables in this model, the statistically significant results are observed in programs with cost-plus contracts. This observation is statistically significant at the 10% level. Since only cost-plus programs yield statistically significant results, the marginal effects of the independent and explanatory variables have only been measured for programs with cost-plus contracts. That the model does not produce statistically significant results for programs with fixed-price contracts implies the existence of additional explanatory variables which are not captured within the scope of this report. For the cost-plus contract programs, according to the population averaged model, the average marginal effect of Log Maturity is 0.21 and for EAC SE/PM cost ratio is 1.00. This means that for a one unit (1%) change in the Log Maturity the likelihood of a cost breach occurring will change by 0.21%. Moreover, for a one unit (1%) change in the EAC SE/PM cost ratio the likelihood of a cost breach occurring will change by 1.00%. Similar to the results in Section C of this chapter, as the EAC SE/PM cost ratio changes from 0.1 to 0.4 there are corresponding changes in the marginal effect on the probability of a cost breach occurring in a program:

- When the EAC SE/PM cost ratio is 0.1, a 1% change in the EAC SE/PM cost ratio positively corresponds to a 0.94% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.2, a 1% change in the EAC SE/PM cost ratio positively corresponds to a 1.08% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.3, a 1% change in the EAC SE/PM cost ratio positively corresponds to a 1.12% change in the probability of a cost breach occurring.
- When the EAC SE/PM cost ratio is 0.4, a 1% change in the EAC SE/PM cost ratio positively corresponds to a 1.07% change in the probability of a cost breach occurring.

E. SUMMARY OF RESULTS

In this chapter we looked at the SE/PM ratios and cost breaches for 32 MDAPs during the period of 1998 to 2011. We noted that the observed SE/PM cost ratios were approximately normally distributed with an average of 0.16 and a range of 0.05 to 0.5. Our graphical analysis indicated that there appears to be a relationship between SE/PM cost ratios and cost breaches as shown in Figure 8. We used multiple models and three types of regression to further examine this relationship: ordinary least squares (OLS) regression, fixed effects (FE) logit and population averaged (PA) logit, as described in Chapter IV. A linear model was used to describe the relationship:

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1 + \beta_2 X_2$$

$$X_0 = \text{EAC SE/PM Cost Ratio}$$

$$X_1 = \text{Log Maturity}$$

$$X_2 = \text{Contract Type}$$

Based on the results of the analysis, using the population averaged logit model to look across programs seems most useful. This is probably due to the population averaged model making longer term observations, whereas the fixed effects model is making short term observations. Of the three variables tested using the various logistic regression techniques, the model which included the explanatory variables Log Maturity and cost-plus contract types had the largest values for the average marginal effects of EAC SE/PM cost ratio: the average marginal effect of Log Maturity is 0.21 and for EAC SE/PM cost ratio is 1.00. Furthermore, in this model as the EAC SE/PM cost ratio changes from 0.1 to 0.4 there are corresponding changes in the marginal effect on the probability of a cost breach occurring in a program.

The analysis results seem to support the hypothesis that high transaction costs are an ex-ante indicator related to MDAP cost breaches. The next chapter will discuss conclusions that can be drawn from these results, as well as research areas which were not captured in this report that may contribute to improving DoD cost estimation.

VI. SUMMARY AND FUTURE RESEARCH

This chapter of the report provides an overview of the salient observations of this research. This includes inferences that can be made based on the key takeaways from the logit population averaged regression, which turned out to be the best method of approach that was considered for modeling the data. As this research only addresses the role that transaction costs play in Department of Defense (DoD) cost estimates, this chapter also presents areas for further research that may help system engineers and cost analysts to improve program cost estimation and possibly use breaches to create a predictive model in the future.

A. CONCLUSIONS

This analysis is based on the assumption that there is a real cost for business negotiations and managing the program, commonly known as transaction costs. We seek to determine (1) if there is a correlation between these transaction costs and acquisition cost threshold breaches; and (2) if cost threshold breaches are related to the *amount*, or proportion of total costs, that are spent on program transaction costs. The data set included major defense acquisition programs (MDAPs) with 10% (or greater) cost threshold breaches. Using logit population averaged regression analysis yielded statistically significant results for the programs with cost-plus contracts. These contracts exhibited relationships between (1) the estimate at completion (EAC) system engineering/program management (SE/PM) cost ratio and the likelihood of a cost breach occurring; and (2) the log maturity and the likelihood of a cost breach occurring.

The results show that as the EAC SE/PM cost ratio rises between 0.1 and 0.3 there is a statistically significant corresponding increase in the probability of a cost threshold breach occurring. This provides answers to both of these research questions. First, the statistically significant correspondence between the variables infers that correlation exists. Second, the relation between cost threshold breaches and the amount of transaction costs is confirmed because as the relative amount of transaction costs for an MDAP increases, the likelihood of the occurrence of a cost threshold breach also increases.

The report also sought to determine whether underestimated transaction costs had contributed to MDAP cost threshold breaches. While the research established correlation between the independent and dependent variables there was no testing for causality. The existence of a correlation between transaction costs and MDAP cost threshold breaches neither suggests that increased transaction costs caused the cost threshold breach, nor that a cost threshold breach generated increased transaction costs. Without establishing causality, it cannot conclusively be stated that underestimated transaction costs have contributed to cost growth for MDAPs.

B. IMPLICATIONS TO SYSTEMS ENGINEERING

It is incumbent upon system engineers (SEs) to understand the cost estimation process for any project or program in order to provide support to the program manager. The SE process is the overarching framework designed to be the "integrating mechanism for… limitations imposed by technology, budget, and schedule" (Defense Acquisition University 2011b, B-264). For the SE effort to be effective, understanding the impact of transaction costs on the acquisition cost of systems is important. Our research informs the SE process by suggesting an association between transaction costs and cost threshold breaches for major defense acquisition programs (MDAPs) with cost-plus contracts.

C. AREAS FOR FURTHER RESEARCH

The logit population averaged model proved to be useful in this research for multiple reasons. Two of the more salient reasons are that (1) logistic regression models are designed for binary-outcome dependent variables; and (2) the data is in panel form, as discussed in Chapter IV. This research strongly suggests that of the three models considered, the logit population averaged model would be useful for future research—particularly for estimating the marginal effect of the independent variable(s) on the dependent variable. That is, the logit population averaged model would be useful for testing the impact of EAC SE/PM cost ratio with other explanatory variables against the probability of a cost threshold breach occurring.

It would be interesting to run logit regressions with more variables in order to increase the explanatory power of the model and determine other factors which may contribute to cost threshold breaches. That the "maturity" of the program, as defined in Chapter IV (Section B) of this report, is related to the occurrence of a cost threshold breach is interesting and may be worthy of further research. In particular, the correlation of log maturity paired with other variables to cost breaches has not yet been explored. Whether by using actual data or proxies, future research of the following for correlation to cost threshold breaches may prove interesting: (1) program complexity; (2) "to date" SE/PM cost ratio; and (3) the degree to which programs are ahead of or behind on schedule.

Tracking MDAP SE/PM cost ratio trends over time to better understand the implications of pre-breach SE/PM cost ratios and post-breach SE/PM cost ratios may also prove useful to program managers. Perhaps the pre-breach SE/PM cost ratio when compared against program acquisition milestones through time is indicative of future breaches. Is it possible that the SE/PM cost ratio is a resource tail for mitigating actions that a program manager may take to avoid or lessen the severity of a cost threshold breach?

Ultimately, considering the association of these independent variables with the dependent variable will be integral to developing a multivariate model that has predictive power for MDAP cost threshold breaches. Such a predictive model would be an invaluable tool for MDAP stakeholders and particularly systems engineers and program managers. It is likely that any future research along the lines essayed in this study involves revisiting the basic model—which is depicted in Figure 2. While it proved useful, it (like all models) is a simplification of the real world. And, it is likely this particular effort has wrung out about all that model can provide by way of insights and explanatory power. Hence, any significant advances in the understanding of transaction costs in defense costs, and their estimation, probably entails the formulation of a richer (and likely more complex) model. That said, we feel that Figure 2 does provide a useful starting point for devising a better model.

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APPENDIX

A. DEFINITION OF TERMS AND VARIABLES

All definitions from DAU Glossary, 2011 found at (https://dap.dau.mil/glossary/Pages/Default.aspx) unless otherwise indicated.

Acquisition Cost Estimate	Equal to the sum of the development cost for prime mission equipment and support items; the procurement cost for prime mission equipment, support items, and initial spares; and the system specific facilities cost.
Component Cost Estimate (CCE).	The generic term ―DoD Component Cost Estimate‖ is used to provide considerable latitude to each military service or defense agency as to the actual responsibility for this cost estimate. In some cases, a military service assigns the responsibility to the Program Office (PO), which then provides a Program Office Life Cycle Cost Estimate (PLCCE). In other cases, the DoD Component may adopt a more corporate approach in which an initial PO cost estimate is subject to considerable review and possible adjustment as determined by the Service Cost Center or defense agency equivalent (Defense Acquisition Guidebook 2011a).
Cost Estimate	A judgment or opinion regarding the cost of an object, commodity, or service. A result or product of an estimating procedure that specifies the expected dollar cost required to perform a stipulated task or to acquire an item. A cost estimate may constitute a single value or a range of values.
Estimate at Completion (EAC)	Actual direct costs, plus indirect costs or costs allocable to the contract, plus the estimate of costs (direct and indirect) for authorized work remaining.
Independent Cost Estimate (ICE).	A Life Cycle Cost Estimate (LCCE) for Acquisition Category (ACAT) I programs prepared by an office or other entity not under the supervision, direction, or control of the military department, defense

	agency, or other Component of DoD that is directly responsible for B-116 development or acquisition of the program, or if the decision authority has been delegated to a Component, prepared by an office or other entity that is not directly responsible for carrying on the development or acquisition of the program.
Independent Government Cost Estimate (IGCE).	An estimate of the cost for goods and/or estimate of services to be procured by contract. Such estimates are prepared by government personnel, i.e., independent of contractors.
Life Cycle Cost	For a defense acquisition program, LCC consists of Research and Development (R&D) costs, investment costs, operating and support costs, and disposal costs over the entire life cycle. These costs include not only the direct costs of the acquisition program, but also indirect costs that would be logically attributed to the program. In this way, all costs that are logically attributed to the program are included, regardless of funding source or management control (Defense Acquisition Guidebook 2011a).
Nunn-McCurdy Breach	Refers to Title 10 U.S.C. § 2433, Unit Cost Reports (UCRs). This amendment to Title 10 was introduced by Senator Sam Nunn and Representative Dave McCurdy in the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 1982. Requires that Acquisition Category I (ACAT I) Program Managers (PMs) maintain current estimates of Program Acquisition Unit B-174 Cost (PAUC) and Average Procurement Unit Cost (APUC). If the PAUC or APUC increases by 25 percent or more over the current Acquisition Program Baseline (APB) objective, or 50 percent or more over the original APB objective, the program must be terminated unless the Secretary of Defense (SECDEF) certifies to Congress that the program is essential to national security (DoDI 5000.02 and Defense Acquisition Guidebook, Chapter 10).
Operation and Maintenance (O&M)	O&M appropriations fund expenses such as civilian salaries, travel, minor construction projects,

	operating military forces, training and education, depot maintenance, stock funds, and base operations support.
Procurement	Procurement appropriations fund those acquisition programs that have been approved for production (to include Low-Rate Initial Production (LRIP) of acquisition objective quantities), and all costs integral and necessary to deliver a useful end item intended for operational use or inventory upon delivery.
Program Office Estimate (POE).	A Component Cost Estimate (CCE) of Life Cycle Costs (LCCs) conducted by an acquisition Program Office (PO).
Research, Development, Test, and Evaluation (RDT&E)	RDT&E appropriations fund the efforts performed by contractors and government activities required for the Research and Development (R&D) of equipment, material, computer application software, and their Test and Evaluation (T&E) including Initial Operational Test and Evaluation (IOT&E) and Live Fire Test and Evaluation (LFT&E). RDT&E also funds the operation of dedicated R&D installation activities for the conduct of R&D programs.
SE/PM Cost	This cost is the sum of recurring and non-recurring costs for the SE/PM WBS line item. This cost is not inclusive of the contractor's or subcontractor's profit/loss or fees.
SE/PM Ratio	This ratio serves as a proxy for transaction costs and is defined to be the program's SE/PM costs divided by total cost:

$$\text{SE/PM Ratio} = \frac{\text{"To Date" SE/PM Costs}}{\text{Total Cost EAC}}$$

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B. USING THE DEFENSE ACQUISITION MANAGEMENT INFORMATION RETRIEVAL SYSTEM

Establishing an account with the Defense Acquisition Management Information Retrieval (DAMIR) system was a fairly simple process. Individual institutions are assigned DAMIR points of contact (POCs) who are responsible for requesting a DAMIR account on behalf of the user. The user is responsible for providing the requisite personal information and justification for use to the institution's DAMIR POC. The DAMIR help desk (phone number found at http://www.acq.osd.mil/damir/index.html) was helpful for establishing the DAMIR account.

Generally, the organized and established criteria for SAR submissions facilitated the effort for finding MDAPs and their associated SARs, but it is important to note that political events can also affect SAR submission. For instance, in years which the president's budget was signed late (e.g., 2000 and 2008) the only SARs found are for MDAPs which met the mandate to submit an interim quarterly SAR, such as a Nunn-McCurdy breach or schedule delay of at least 6 months.

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C. USING THE DEFENSE COST AND RESOURCE CENTER

It requires approximately one week to establish a Defense Cost and Resource Center (DCARC) account and access the cost and software data reporting (CSDR) database. Using the online registration instructions found at the DCARC Knowledge Portal (http://dcarc.cape.osd.mil/) made the process simple. The access levels that are required to view the CSDR information used in this report are "DACIMS35_Analyst" and "EVM_Analyst." Once the user's CAC card is registered with DCARC, access will be granted to the database. Access to DCARC also includes access to the Defense Automated Cost Information Management Systems (DACIMS) 3.5 Library. The CSDR library contains folders of active and inactive MDAP contract data sorted by weapon system types. More specifically, contract information within each of these folders includes: the DD Form 1921 (Cost Summary Data Report), the DD Form 1921–1 (Functional Cost-Hour Report) and the contract work breakdown structure (CWBS) Index and Dictionary among other documents.

1. Sample Cost Data Summary Report (DD Form 1921)

The cost data summary report (Figure 10) comprises many categories of program metadata and reported data. A list of these categories and detailed information about the DD Form 1921 can be found in DI-FNCL-81565C.

SECURITY CLASSIFICATION ______________________________

COST DATA SUMMARY REPORT

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 8 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE ABOVE ORGANIZATION.

1. PROGRAM a. MDAP: b. PHASE:	**2. PRIME MISSION PRODUCT**	**3. CONTRACTOR TYPE** *(X one)* ☐ PRIME/ASSOCIATE ☐ DIRECT-REPORTING SUBCONTRACTOR	**4. NAME/ADDRESS** *(Include ZIP Code)*	**5. APPROVED PLAN NUMBER**
6. CUSTOMER *(Direct-Reporting Subcontractor Use Only)*	**7. CONTRACT TYPE** / **8. CONTRACT PRICE**	**9. CONTRACT CEILING**	**10. TYPE ACTION** a. CONTRACT NO.: b. LATEST MODIFICATION: c. SOLICITATION NO.: d. NAME:	
11. PERIOD OF PERFORMANCE a. START DATE *(YYYYMMDD)*: b. END DATE *(YYYYMMDD)*:	**12. APPROPRIATION** ☐ RDT&E ☐ PROCUREMENT ☐ O&M	**13. REPORT CYCLE** *(X one)* ☐ INITIAL ☐ INTERIM ☐ FINAL	**14. SUBMISSION NUMBER** / **15. RESUBMISSION NUMBER**	**16. REPORT AS OF** *(YYYYMMDD)*
17. NAME *(Last, First, Middle Initial)*	**18. DEPARTMENT**	**19. TELEPHONE NUMBER** *(Include Area Code)*	**20. EMAIL ADDRESS**	**21. DATE PREPARED** *(YYYYMMDD)*

WBS ELEMENT CODE A	WBS REPORTING ELEMENTS B	NUMBER OF UNITS TO DATE C	COSTS INCURRED TO DATE			NUMBER OF UNITS AT COMPLETION G	COSTS INCURRED AT COMPLETION		
			NONRECURRING D	RECURRING E	TOTAL F		NONRECURRING H	RECURRING I	TOTAL J
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00
					0.00				0.00

22. REMARKS

DD FORM 1921, APR 2007 PREVIOUS EDITION IS OBSOLETE. SECURITY CLASSIFICATION ______________________ Adobe Professional 7.0

Figure 10. Cost Data Summary Report (Blank)

2. Steps for Estimate at Completion SE/PM Cost Ratio Calculation

- Determine the SE/PM cost. Identify the line item for "Systems Engineering/Program Management" in the column for "WBS Reporting Elements" (Column B). Record the "Total" estimate at completion cost for Systems Engineering/Program Management (Column J).
- Determine the EAC total cost. Identify the "Total Cost (Less Profit or Fee)" in the column for "WBS Reporting Elements" (Column B). Record the "Total" estimate at completion cost for EAC total cost (Column J).
- Determine the SE/PM cost ratio. Divide the SE/PM cost (Step 1) by the EAC total cost (Step 2). Record the SE/PM cost ratio value.

D. PROGRAM LIST AS REPORTED IN SELECTED ACQUISTION REPORT (SAR)

Active Electronically Scanned Array (AESA) Radar
AIM-9X/Short Range Air-to-Air Missile
AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)
AN/WQR-3, Advanced Deployable System (ADS)
Apache Block IIIA Remanufacture (AB3A REMANUFACTURE)
AV-8B/Attack, V/STOL, Close Air Support (Harrier II+ Remanufacture)
B-2 Radar Modernization Program
Cobra Judy Replacement (Cobra Judy Replacement)
EA-18G Growler (EA-18G)
Expeditionary Fighting Vehicle (EFV)
E-3 AWACS Radar System Improvement Program (RSIP)
E-2C Reproduction
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)
Family of Medium Tactical Vehicles (FMTV)
Guided Multiple Launch Rocket System/DPICM/Unitary/Alternative Warhead (GMLRS/GMLRS AW)
Joint Common Missile (JCM)
Joint Tactical Radio System Ground Mobile Radio (formerly Cluster 1) (JTRS GMR)
Longbow Hellfire - subsystem of the AH-64 Apache Weapon System
LHA Replacement Amphibious Assault Ship
MQ-4C Unmanned Aircraft System Broad Area Maritime Surveillance (MQ-4C UAS BAMS)
Multi-Platform Radar Technology Insertion Program (MP-RTIP)
National Polar-orbiting Operational Environmental Satellite System (NPOESS)
Presidential Helicopter Replacement (VH-71) Program
P-8A Poseidon
Sense and Destroy Armor (SADARM)
Small Diameter Bomb Increment II (SDB II)
Space Based Infrared System (SBIRS) High Program
Standard Missile (SM) - 2 Block IV
Stryker Family of Vehicles (STRYKER)
UH-72A Light Utility Helicopter (LUH)
Warfighter Information Network - Tactical (WIN-T)

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